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IGNEOUS METAMORPHISM OF COAL BEDS.

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ON the eastern margin of the Yampa coal field, in Routt County, Colorado, there are many intrusions of igneous rocks north of Yampa River which have afforded the writer exceptional opportunities for a study of the effect of contact metamorphism on the coal beds. In the localities observed by the writer the intrusive masses are olivine basalt with a density ranging from 2.65 to 2.95, and they occur in the form of sills varying from 10 to 300 feet in thickness. In the middle portion of the sill the basalt is homogeneous and appears to represent a single flow. Occasionally, near the sides, the sill splits into several thin sheets. In many places the intrusive mass lies in a rich coal zone with many small beds of coal to mark the degree of carbonization above and below the sill. In the heat-zone created by the basalt sill, every stage of carbonization of the coal above that of bituminous was noted. In direct contact with the basalt the coal has a specific gravity, when corrected for ash, as high as 1.89.

The Basalt Sheets.—The basalt sheets, in general, are concordant with the planes of stratification, but in places they cut across the measures and are found in several distinct coal zones. As a number of deep diamond core-drill holes were put down in these areas, it is possible to determine whether the basaltic intrusion came in by assimilating certain strata or by displacement of the sedimentary beds.

In one case the basalt sill is 225 feet thick and occurs in the strata between the Wadge and Wolf Creek coal beds. At this

location the drill shows a total thickness of 149.4 feet of sedimentary strata between these beds in addition to the basalt. The sill is overlain by sandy shale and underlain by clay shale. Within a radius of three-quarters of a mile seven drill-holes show the undisturbed strata in this interval to range from 131.6 feet to 147.2 feet, with an average of 142.8 feet. In these holes the coal beds are undisturbed as the basalt was intruded in lower beds. In the case first mentioned the basalt apparently did not assimilate any of the strata that it penetrated because the sedimentary beds are 6.6 feet thicker than they are in surrounding drill-holes where no volcanic sill was found. (All measurements are corrected for dip and represent thickness at right angles to bedding planes.)

In the second case the basalt sill was intruded between the Wolf Creek and a lower coal bed, known locally as the "Small Anthracite." Here the basalt is split into six sheets totaling 84.2 feet in thickness, and the sedimentary beds consist of four beds of shale and two of sandstone, totaling 25.6 feet in thickness. Six drill holes in adjacent areas show the interval between these two coal beds, free from basalt intrusions, to vary from 35.0 to 41.3 feet, averaging 37.9 feet. This indicates 9 to 11 feet of the strata were assimilated by the intrusive mass.

In the third case a basalt sill 142 feet thick lies between the Small Anthracite and the upper Block coal bed. The sill is overlain and underlain by shale. The sedimentary beds here total 41.9 feet. Three other drill-holes show the interval between the coal beds to average 45.7 feet with no basalt intrusions present. This indicates a possible assimilation of 3 to 4 feet of sedimentary beds. In this particular case I think a thin bed of sandstone was assimilated by the lava as, in the other holes nearby, a three-foot sandstone occurs at the horizon of the volcanic sill.

Effects of the Sills.—In the area under consideration it was noted that the main body of the sill produced a fairly uniform heat zone above and below. In general it was noted that coal is carbonized to anthracite both above and below the volcanic sill from one-quarter to one-third the thickness of the sill. On the edges of the sheet the heat zone is erratic. In a drill-hole on the

west edge of the sill a small bed of coal 29.2 feet above a basalt sill 19.5 feet in thickness was metamorphosed to coal having a fixed carbon content on the pure coal basis of 69.30 per cent. This sheet was probably a flow channel or conduit.

In a drill-hole a mile away on the east edge of the lava field a sill 307 feet in thickness had barely metamorphosed a small bed of coal 30 feet below it. In this case I think the lava was near the end of its journey and was, perhaps, already partially solidified. It perhaps flowed so slowly that the surrounding rocks absorbed the heat with no great rise in temperature.

In the central area of a sill anthracite was found as far below the sill as above it, showing that heat penetrated downward as readily as upward. However, the zone of discernible metamorphism extended upward considerably farther than downward.

In several holes the basalt sill is almost directly under the big Wolf Creek coal bed and in such a situation it has changed the coal into super-anthracite. The porous super-anthracite must be a very poor conductor of heat as the zone of anthracization here extends farther below than above the sill. In one hole where the Wolf Creek coal bed is directly beneath a big basalt sill, metamorphism extended 160 feet above the sill and only 95 feet below it.

The best anthracite was found at one-seventh the thickness of the sill above and below it. One coal bed at this distance above the sill shows 13,733 B.t.u.'s; another coal bed one-seventh the thickness of the sill above it is the strongest coal found, showing a compressive strength of 8142 pounds per square inch and a modulus of elasticity of 365,400 at 2000 pounds per square inch and 383,670 at 4000 pounds per square inch. This coal had nearly the same proximate analysis as anthracite from the Mammoth bed, Lansford, Pennsylvania, and also the same specific gravity, 1.563. Both these coals carry only .6 per cent. of moisture on the air-dried basis. As the coal bed approaches the basalt sill, the moisture content and also the specific gravity slowly increases.

The principal drill-holes in the central area of the basalt sill,

where the metamorphism above and below is fairly uniform, were integrated to show a generalized section, shown in Fig. 1.

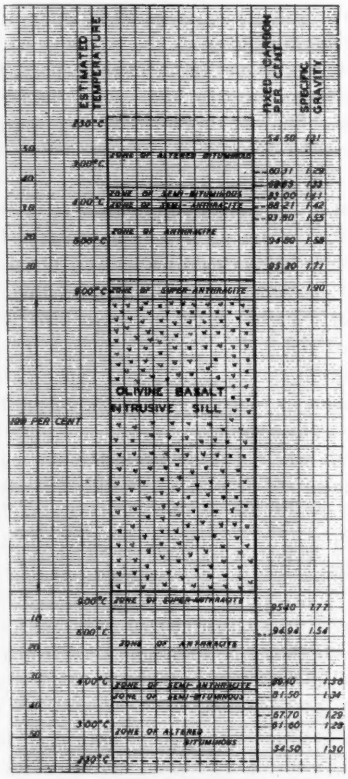


FIG. 1. General section showing igneous metamorphism of coal beds.

All coal beds and small seams in the zone of discernible metamorphism were analyzed in the electric furnace for moisture, volatile matter, fixed carbon, and ash. Most of the coal is very

low in ash; in cases where the coal carries calcite the volatile matter was corrected for carbon dioxide. Over two hundred proximate analyses were used in compiling this section. The following are typical analyses of the unaltered coal in the area in question:

Wolf Creek Bed		*Block Bed*	
Moisture	2.9%	Moisture	9.6%
Volatile matter	40.3%	Volatile matter	36.6%
Fixed carbon	47.8%	Fixed carbon	50.6%
Ash	9.0%	Ash	3.2%
	100.0%		100.0%
Sulphur: 0.54%; B.t.u.'s, 12,255.		Sulphur: 0.48%; B.t.u.'s, 12,060.	

Wadge Bed

Moisture	6.0%
Volatile matter	38.0%
Fixed carbon	50.1%
Ash	5.9%
	100.0%

Sulphur: 0.40%; B.t.u.'s, 12,167.

Density Changes.—It is apparent from these tests and also from density determinations made on all the coal beds found in drill holes that the coal increases in density as the sill is approached; a regular increase in the moisture content of the coal was noted in coal beds within a short distance of the basalt sill.

Samples of low-rank bituminous coal and semi-anthracite, when heated in the laboratory to successively higher temperatures, also show a rather uniform increase in density. The first tests made in the laboratory gave results which indicate that the coal near the basalt contact had been heated to well over 1200° C., and the coal just inside the zone of anthracization had been heated to about 530° C. Later more complete temperature tests were made by the writer and also by the Bureau of Standards at temperatures varying from 1500° C. to 2415° C. These indicate the coal density curve turns downward beyond 1000° C.

I also found that to get comparable results in specific gravity determinations, the coal specimens had to be dried at 105° C. and

immersed in water for from one to twenty days before the available cell space or voids in the specimen were filled with water. Even pulverized coal requires several hours' immersion in water to fill the pores. All pieces selected for heating tests were about three grams in weight and were heated in an electric furnace chamber one and one half inches in diameter by six inches deep. They were inclosed in special porcelain crucibles with tight-fitting covers. The bottom of the crucible was just over the thermocouple of the pyrometer. The tests showed a negligible amount of oxidation.

The Bureau of Standards high-temperature determinations

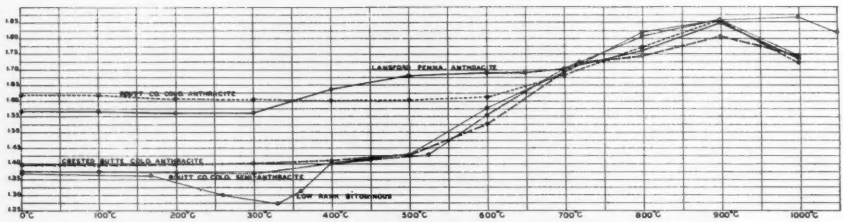


FIG. 2. Specific gravity of coals heated to temperatures 0° to 1000° C.

were made in a high-frequency electric furnace. The coal was heated in two graphite crucibles placed one inside the other in such a position that the coal could be observed by an optical pyrometer through small holes drilled in the two crucible covers. In all tests the coal was held at the desired temperature for one hour in the low ranges, for shorter periods in the higher temperature ranges, and for five to seven minutes in temperatures ranging from 1500° C. to 2415° C.

Laboratory Tests.—Five coals were selected for laboratory tests: (1) A high grade Routt County anthracite found 42 feet below a 285-foot basalt sill; (2) A high grade low-ash Routt County, semi-anthracite, found above a big basalt sill; (3) High grade, low-ash Pennsylvania anthracite from the Mammoth bed, Lansford, Pa.; (4) Crested Butte, Colorado anthracite, formed

partially by contact metamorphism but principally by regional pressure metamorphism; (5) A low-rank upper Mesaverde bituminous coal from near Hayden, Colorado. This coal is classed as on the border line between sub-bituminous coal and bituminous.

Fig. 2 shows the specific gravity of the coals at temperatures ranging from 100° C. to 1000° C.

Fig. 3 shows result of tests made on the volatile matter emitted at 100° C. intervals up to 1000° C. on one Pennsylvania and three Colorado anthracites.

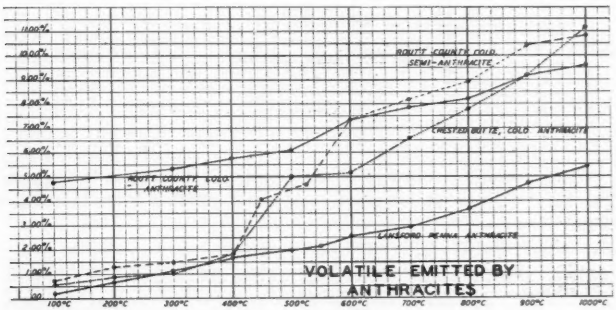


FIG. 3. Volatile emitted by anthracites heated from 100° C. to 1000° C.

Fig. 4 shows volatile matter emitted by Colorado anthracite. The volatile matter emitted consists of moisture in the cell space of the coal, water of hydration in the sulphates, volatile hydrocarbons and, in the case of the coal heated from 1500° C. to 2415° C., nitrogen and part of the ash that was volatilized. Anthracite decrepitates violently in the carbon arc. However, using coke with 6 per cent. ash and heating for a few seconds in a carbon arc, the ash was volatilized without affecting the subsequent structure or combustibility of the coke. I estimated that it required temperatures of 2700° C. to 2800° C. to completely volatilize the ash. Another test was made to show the percentage of water taken up by immersed coal heated to differ-

ent temperatures. On the high temperature test pieces, ash analyses show the loss of ash at different temperatures.

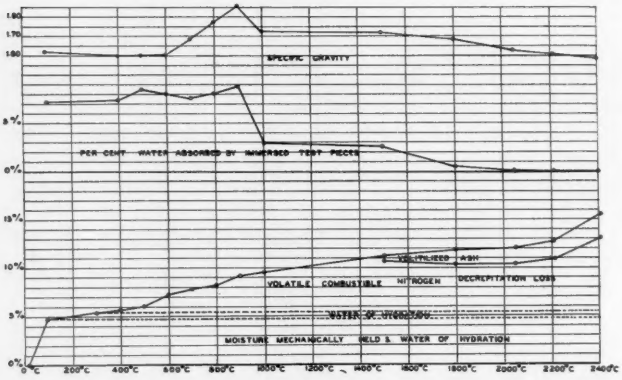


FIG. 4. Volatile emitted by Routt County, Colo., anthracite from 20° C. to 2415° C., also specific gravity and water absorbed by immersed test pieces.

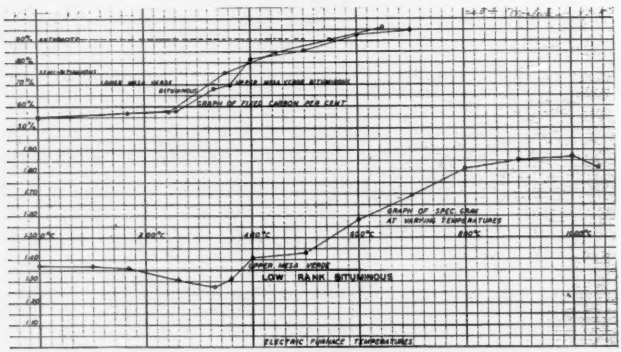

GRAPH OF FIXED CARBON PER CENT
GRAPH OF SPEC GRAV AT HEATING TEMPERATURES
LOW RANK BITUMINOUS
ELECTRIC FURNACE TEMPERATURES

FIG. 5. Results of tests on low-rank bituminous coal.

Fig. 5 shows result of tests on low-rank bituminous coal; a specific gravity determination and then a proximate analysis was

made of each test piece to show the percentage of fixed carbon. On this low-rank coal a temperature of 168° C. caused a definite change in the fixed carbon content.

From a careful consideration of these curves, it would seem that coal within one foot of the basalt has been heated to about 1000° C.

The high-grade anthracite, showing a fixed carbon content of 94.5 per cent., was probably subjected to a temperature of about 600° C. The coal on the dividing line between anthracite and semi-anthracite was subjected to a temperature of 350 to 400° C. and the regional bituminous coal having a fixed carbon content of 54.5 per cent. showed no change below 160° C.

The density curve of Lansford, Pa., anthracite shows a strong break upward before reaching 400° C.

Super-anthracite from Cranston, Rhode Island, is somewhat similar in character to the Colorado super-anthracite found in contact with the basalt sills. Its specific gravity corrected for ash is somewhat higher than anything found in northwestern Colorado or produced by reheating in a laboratory furnace. Its pore space of 4.5 per cent. indicates that it was formed by metamorphism at a temperature of about 900° C. It is almost converted into graphite.

The Poolsville, Maryland, super-anthracite, supposed to be Triassic coal anthracitized by a large diabase dike, after being corrected for ash, has a specific gravity of 1.68, corresponding to coal heated to 1800° C. This coal carries absolutely no moisture; this alone indicates that it must have been heated to a high temperature. Its hardness, luster, and fracture correspond exactly to laboratory specimens heated above 2000° C.

Fig. 6 is the actual log of a drill-hole showing location and analyses of the coal beds encountered.

In places where the coal is in direct contact with the basalt, calcite, gypsum, and alunite are often found on the joint planes. In one drill-hole, coal at the basalt contact has the following proximate analysis:

	Per Cent.
Moisture	11.1
Volatile matter	9.2
Fixed carbon	62.8
Ash	16.9
	100.0

Sulphur determined separately: 0.85 per cent.; heating value, 9160 B.t.u.'s.

This gives a fixed carbon content on the pure coal basis of 87.2 per cent., which would class this coal as semi-anthracite. Actually the coal is, of course, super-anthracite.

The normal ash content of this particular coal is 16 per cent. of the fixed carbon, making for this sample 10 per cent. normal ash. This leaves 6.9 per cent. of the ash as calcium oxide from the calcite which would account for 5.4 per cent. of carbon dioxide in the volatile matter. The 0.85 per cent. sulphur in the form of calcium and aluminum sulphate would hold .6 per cent. of water of hydration and then, at higher temperatures, decompose and yield oxygen to combine with the carbon and give about 1.2 per cent. of carbon dioxide; this would reduce the combustible volatile to 2.0 per cent. As the heating value of this sample is 9160 B.t.u.'s the 62.8 per cent. of fixed carbon accounts for 8860 B.t.u.'s; 2 per cent. low-grade volatile combustible matter would account for the remainder. When the intrusive lava came in contact with the coal, probably all of the volatile matter was driven off except nitrogen, and this nitrogen is perhaps the base of the small percentage of volatile combustible matter formed later in the super-anthracite.

Conclusions.—Specific gravity determinations made on bituminous and anthracite coals, together with tests of water absorbed by immersed coal specimens, indicate that the change from low-rank bituminous to anthracite is accomplished at temperatures ranging from 160° C. to 350° C. The change from 90.9 per cent. to 95 per cent. of fixed carbon probably takes place at 350° C. to 600° C. Above 600° C. the pores of the coal seem to open, but at 900° C. the pores begin to close, and at 2400° C. the coal is im-

pervious to moisture. Aside from this there is very little change in anthracite heated from 600° C. to 2400° C.

It would appear that the woody texture is retained by the coal in all stages of metamorphism from lowest rank to coal heated in the electric arc until every vestige of ash is volatilized. The tree exudes gum to protect its living cells from air and water. In the change from low-rank bituminous to high-rank bituminous a similar process apparently takes place. All coal consists essentially of more or less perfect cell structures connected by capillary passageways. At 200° C. the tarry constituents of the coal begin to melt and partially clog the passages between the cells, at about 330° C. the heavy tars melt and the cell voids are effectually protected from the ingress of water. With still higher temperatures the heavy tars exude and cement the prismatic joint planes forming a perfect anthracite. This is coal at its best—a smokeless fuel, impervious to air and moisture so it will stand weathering for years without appreciable deterioration. It also has great compressive strength and a high modulus of elasticity which enable it to stand handling with but little breakage.

With higher temperatures the heavy tars begin to volatilize again, reopening the capillary passages and weakening the cement. At about 800° C. the coal loses strength and ability to withstand weathering; it is distinctly inferior and should be classed as superanthracite. Much of the Colorado coal in close proximity to the volcanic sills and the Rhode Island anthracite are in this category. They are characterized by high specific gravity, high moisture, and low heating value.

At about 1000° C. the ash constituents of the coal begin to melt and again seal the capillary passages and the coal becomes more and more impervious to moisture, is of low specific gravity, and increases greatly in hardness and luster. Brilliant, hard superanthracite from Poolsville, Maryland, is a good example of this stage of metamorphism.

The theory of sealing of the capillary system connecting the original plant cells by tar and resin compounds explains many features of the behavior of coal. It is a well known fact that

good coking coal is largely wood remains and has a well developed cell structure to begin with; the coal is far enough advanced in rank so that the intercellular passages are blocked with tarry compounds. When sudden heat is applied the cells swell before the tar in the passages melts and releases the volatile in the cells. All coking coals contain only a small percentage of moisture.

Gas-bursts in mines where coal is blown into the workings, often in a finely divided state, may be due to accumulations of gas in the cell voids under tremendous pressure. In this state the inter-cell passages are completely choked so the gas has no chance to escape and the pressure increases until the cell walls are disrupted and the coal virtually explodes. Semi-anthracite, when heated for volatile determinations, invariably deflagrates with such violence that fine dust is blown out of the crucible. Because of this behavior I found it necessary to use a coarsely crushed sample to avoid deflagration losses. Coal containing a high percentage of moisture has a very open structure and gas and water pass in and out readily. Because of this condition gas pressure can not build up in the cell structure. Mines in low-rank bituminous coal are non-gaseous. Low moisture coals have closed cell-structure and mines opened in them are usually gaseous.

On long immersion in water, dried specimens of the different coals take up the following percentages of water:

	Per Cent.
Upper Mesaverde bituminous	15.60
Lower Mesaverde bituminous	9.25
Lower Mesaverde metamorphosed to 60% F.C.	4.40
Lower Mesaverde metamorphosed to semi-anthracite	.98
Crested Butte anthracite	2.40
Lansford, Penna. anthracite	1.44

Semi-anthracite shows the lowest absorption of water and in the Routt County field outcrops of this coal weather very little. They are generally marked by glittering pieces of coal lying on the surface.

The process of carbonization above and below the sill shows that sandstone and shale are better conductors of heat than coal, the heat traveling two to four times farther through the rock than through coal.

Fig. 7 shows the shrinkage of bituminous beds when metamorphosed to anthracite and super-anthracite. The results shown were obtained by averaging the thickness of the beds in drill-holes and prospect tunnels. Owing to variations in thickness and stratigraphic position of the basalt sill, the same coal bed would be found as bituminous in some diamond drill-holes and as semi-anthracite and anthracite in others.

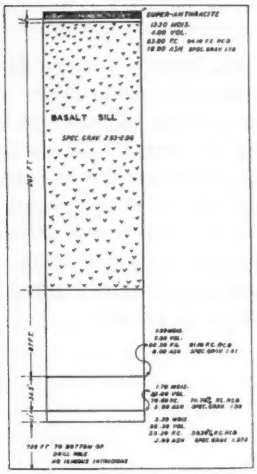


FIG. 6 (left). Drill-hole log showing igneous metamorphism of the coal beds.

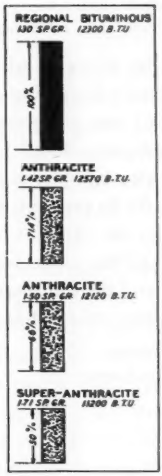


FIG. 7 (right). Shrinkage of coal beds by igneous metamorphism.

The strength of coal is greatly affected by contact metamorphism. Compressive tests made on 2-inch cubes at the Colorado School of Mines gave the following results:

		Compression
Middle Mesaverde bituminous coal,	55% F.C.—Pure coal basis,	3,664 lbs. per sq. in.
Lower Mesaverde bituminous coal,	58% F.C.—Pure coal basis,	1,385 lbs. per sq. in.
Lower Mesaverde bituminous coal,	69% F.C.—Pure coal basis,	847 lbs. per sq. in.
Lower Mesaverde bituminous coal,	72.8% F.C.—Pure coal basis,	335 lbs. per sq. in.
Lower Mesaverde semi-bituminous,	81.5% F.C.—Pure coal basis,	797 lbs. per sq. in.
Lower Mesaverde semi-anthracite,	87.0% F.C.—Pure coal basis,	1,051 lbs. per sq. in.
Lower Mesaverde semi-anthracite,	89.0% F.C.—Pure coal basis,	3,720 lbs. per sq. in.
Lower Mesaverde semi-anthracite,	90.0% F.C.—Pure coal basis,	3,980 lbs. per sq. in.
Lower Mesaverde anthracite,	91.5% F.C.—Pure coal basis,	3,918 lbs. per sq. in.
Middle Mesaverde anthracite,	95.0% F.C.—Pure coal basis,	8,142 lbs. per sq. in.
Lower Mesaverde super-anthracite,	————————	2,754 lbs. per sq. in.

From the above it will be noted that igneous metamorphism tends from the beginning to make the coal tender and friable. As the rank of coal progresses, prismatic jointing and cleavage become more pronounced. At about 85 per cent. F.C., pure coal basis, the cleavage planes are recemented and the coal is less easily broken. At 89 per cent. to 90 per cent. the coal is again equal in strength to the original bituminous from which it was derived. However, all the joints and cleavage planes are not thoroughly recemented and the test pieces do not show a uniform strength until the percentage of fixed carbon increases to 94 per cent.

Oak Creek,
Colorado.

STRUCTURAL CONTROL OF ORE DEPOSITION

CARLTON D. HULIN.

"Ore is where it is, not purely by chance, but by the result of definite processes which operated under certain conditions within the crust of the earth." [1]

INTRODUCTION.

A DEFINITE understanding of the factors which have controlled the formation of ore shoots in metalliferous deposits is one of the most important of the objectives of economic geology. Despite this fact, however, but little advance has been made within recent years in our knowledge concerning the origin of ore shoots. And it may be added that our knowledge in this regard is practically nil.

Despite our scant understanding of the causes of ore shoots, however, a voluminous literature descriptive of ore shoots has been developed. A perusal of even a portion of this discloses the fact that ore shoots of the same type are characterized by certain similarities the world over. So strikingly is this true that the writer has long since discarded the old adages that "ore is where it is" and that "each district is a law unto itself in the localization of its ore shoots" and has substituted that quoted at the beginning of this paper.

If it be recognized, as it must be, that ore shoots are not chance phenomena, but result through the action of definite natural causes, it must follow that these causes, subject possibly to some slight local modifications, will hold universally for a given type of ore shoot.

Lindgren [2] has subdivided ore shoots into magmatic segregation shoots; metamorphic shoots; replacement shoots; shoots of ascending circulation; and vadose shoots.

[1] A. M. Bateman, ECON. GEOL., vol. 14, p. 640, 1919.

[2] W. Lindgren, ECON. GEOL., vol. 4, pp. 56–61, 1909.

This paper deals primarily with the "shoots of ascending circulation"; that is, with primary ore shoots of epigenetic deposits which have formed through the action of solutions or emanations. Replacement shoots are not directly considered, although the writer feels that many shoots have been so designated which have in reality formed otherwise.

PRESENT THEORIES OF ORE SHOOT CONTROL.

Various geologists have from time to time advanced theories concerning possible controls of ore shoot localization. While many of the theories that have been put forward appear reasonable when referred to a particular deposit, very few possess the virtue of general applicability. It seems desirable to mention briefly at this time the more important of the current theories of ore shoot control.

The occurrence of ore shoots at vein intersections is so commonplace as to need no further introduction. Though all vein intersections are not loci for ore shoots, many important ore shoots are so located. Such shoots have been explained as resulting from the increased brecciation at the intersection; as due to mixing of solutions at the intersection; or as the result of stagnation of the solutions. No convincing argument has ever been put forward in support of any of these possible causes. More recently Howe has pointed out that the common occurrence of ore shoots at vein intersections suggests a mechanical cause.[3]

The occurrence of ore shoots at the intersection of veins and cross-faults or fissures is closely akin to the occurrence of shoots at vein intersections. Ore shoots may be localized in the vein in the vicinity of a cross-fault, or the shoots may be terminated by the fault. The cross-fault or fissure may be a plane of considerable movement, or may be merely a minor joint plane. Explanations offered to account for the occurrence of ore in the vicinity of cross-faults have been essentially the same as those offered in explanation of the occurrence of ore shoots at vein intersections.

[3] E. Howe, "The Gold Ores of Grass Valley, California," ECON. GEOL., vol 19, p. 601, 1924.

Wall rock control has been a popular cause advanced in explanation of ore shoots. Such control may be subdivided into control resulting from the chemical nature of the wall rocks, and control by the physical nature of the wall rocks. Chemical control implies a precipitating or catalytic action by the constituents of the wall rocks and has been suggested as a possible cause of ore deposition by many workers. In various cases basic igneous rocks, ferromagnesian minerals, organic matter and metallic sulphides have been held to be favorable precipitants or catalyzers. Though chemical wall rock control may well be a modifying factor in ore deposition, other and more fundamental causes are held by the writer to be operative, excepting, possibly, the case of replacement ore shoots occurring in relatively soluble rocks. Five different cases have come to the attention of the writer where wall rock control of the ore deposition had been postulated. In each case detailed geologic studies disclosed that other causes were of paramount importance, the possible precipitating effects of the wall rocks being negligible.

The tendency of different wall rocks to behave differently on fracturing has led to the theory of a control dependent on the physical nature of the wall rocks. Practically all known rock types however are somewhere known to be hosts to ore shoots. Insofar as different rocks may fracture in a more favorable or less favorable manner the physical nature of wall rocks may be an important modifying factor, but beyond this it can hardly be considered to be of fundamental importance in controlling the location of ore shoots.

Other factors which have been put forward as possible ore shoot controls include the presence of channels of circulation; the damming action of fault gouge; the precipitating action of jets of gas encountered by the mineralizing solutions; stagnation of the mineralizing solutions; and recurrent mineralization.

The growth of the zonal theory in recent years has offered a new explanation for the deposition of ores; it does not however account for the isolation of ore into definite shoots. According to the zonal theory the deposition of the ore minerals, and indeed

of all the materials deposited by the mineralizing solutions, is a direct function of decreasing temperature and pressure resulting from the ascent of the solutions towards the earth's surface.

The inability of current theories to offer a sound explanation for the occurrence of ore shoots must be manifest. Let us picture the common case of a vein containing five or six ore shoots along its length, of which one may occur at a vein intersection, another at an intersection of the vein with a cross-fissure, while the rest are scattered apparently at random along the vein. The shoots have formed at the same time, have received the same mineralization, and shoots and barren portions of the vein are crossed indiscriminately by the same wall rock horizons. Current theories either fail dismally to explain such an assemblage of ore shoots, or force us to assume a different origin for each, which last is manifestly absurd. Ore shoots showing the same mineralization, and occurring in the same vein or region, must manifestly have resulted from the action of the same set of controlling factors.

THE FORMATION OF ORE SHOOTS.

The mode of formation of ore shoots is intimately bound up with the mode of formation of veins. A detailed study of the ore shoots with which the writer is familiar, coupled with a study of those shoots which have been adequately described in the literature, indicates that all shoots of vein deposits, excepting only those formed directly by replacement in easily soluble rocks, have the same fundamental characteristics. An analysis of these characteristics common to ore shoots, which will be considered in detail later, leads to the following conclusions concerning the control of ore deposition and the formation of ore shoots:

The deposition of the minerals of vein deposits, following the zonal theory, is fundamentally a function of concentration, temperature and pressure. As the mineralizing solutions ascend, decreasing temperature and pressure result in supersaturation, with consequent deposition of the various mineral components from time to time.

Ore shoots are developed in these parts of the vein which are open to the passage of solutions at the time of the introduction of the valuable metallic minerals, conditions for deposition being favorable. In general the minerals of the common heavy metals, excepting for the moment the minerals of tin and tungsten, are introduced late in the sequence of mineralization. The early introduced material of the vein usually consists solely of barren quartz. This seals the existing vein fissures, forming barren quartz veins which remain barren unless subsequently reopened. Ore shoots are formed where the early barren quartz veins are brecciated and reopened by intermineralization fault movements at a time immediately preceding the advent of the metallizing solutions. The location of ore shoots is thus directly dependent on favorable local structure of such nature that when affected by intermineralization fault movements brecciation and reopenings of the vein are produced.

In short, *the deposition* of ore is dependent on the physical-chemical conditions of temperature, pressure and concentration of the mineralizing solutions, while the control of *the locus of deposition* is mechanical, being dependent on favorable local structure coupled with fault movements occurring at the proper time during the sequence of mineralization.

FAULTING IN MINERALIZED REGIONS.

The importance of pre-mineral faulting in mineralized regions has been largely underestimated by geologists, and the prevalence of faulting contemporaneous with the mineralization has almost escaped detection. Workers have been prone to class all faults along which vein offsets occur as being post-mineral without further thought.

An offset of a vein by a cross-fault, or the presence in mineralized regions of gouge-filled fissures, themselves unmineralized, cannot be accepted as proof of post-mineral origin for such faults and fissures.

Faults which have successfully developed a filling of gouge are practically immune from the effects of later mineralization.

Fault gouge behaves as a chemically inert substance, and is practically impervious to the passage of solutions. As a result, gouge-filled fissures may retain their pre-mineral characteristics while neighboring fissures free from gouge are being transformed into solid veins. Ransome has recorded this possibility in the literature.[4]

The writer has made detailed studies of some hundreds of vein displacements along cross-faults in which the displacements resulted from pre-mineral dislocation of the vein-fissure, the vein-filling being introduced into the fissure subsequent to the displacement.

The type of evidence which the writer has used in identifying pre-mineral faults includes the following:

(1) Different behavior of the vein on the two sides of the fault. The differences may be in thickness, in value, in the nature (proportion) of the introduced minerals, or any combination of these.

(2) Banding in the vein turning and paralleling the cross-fault at the end of the vein segment. Although this feature is common, it is not prevalent, being frequently destroyed by movements on the cross-fault occurring contemporaneously with the mineralization.

(3) The presence of stringers and veinlets cutting the fault gouge, or partial silicification of the gouge. These features are seldom to be observed more than a few feet from the vein. The veinlets may cut through the gouge, but are more common along the boundary between the gouge and the wall rocks. Such veinlets and stringers are frequently brecciated by slight intermineral or post-mineral fault movements and have unquestionably been commonly classed as "drag ore."

(4) Sealing of the fault line immediately adjacent to the vein by vein-matter. Due to such sealing many faults are practically not discernible where they cut the vein.

(5) Presence of actual veins along the cross-faults. This of

[4] F. L. Ransome, "Relation Between Certain Ore-Bearing Veins and Gouge-Filled Fissures," ECON. GEOL., vol. 3, pp. 331–337, 1908.

course is possible only where the fault was more or less open during the mineralization.

Spurr has pointed out that igneous activity, faulting and ore deposition are related phenomena, and that the faulting usually starts before the mineralization, but greatly outlasts the mineralization, reaching a peak long after the mineralization has ceased.[5] A part of the evidence put forward in support of the importance of post-mineral faulting is to the effect that major fault lines are infrequently the hosts to productive veins, in consequence of which they are believed to have developed in post-mineral time.

The preceding argument has brought out, however, that major fault lines may in general be expected to be less favorable sites for vein formation than other minor fissures, due to the amount of movement the major lines have suffered, and the consequent amount of inert and impermeable gouge developed therein.

Some inter-relation between igneous activity, mineralization and faulting appears to be fairly well established. In some mineralized regions there has undoubtedly been a later independent period of faulting superimposed on the faulting related to the mineralization. Considering only the period of faulting which is related to the mineralization, however, it has been the writer's experience to observe that this faulting commences earlier than the mineralization, reaches a maximum by the middle of the period of mineralization, and then gradually declines, commonly however, outlasting the mineralization. This sequence holds for many important mining regions, including the Mother Lode and Randsburg regions of California, the Telluride and Silverton regions of Colorado, and the Pachuca region of Mexico, and is believed to be a general condition elsewhere.

Our knowledge of the behavior of faults gained from the Elastic Rebound Theory[6] is that the total displacements now shown by faults have resulted through numerous small movements, these small movements being spread over a long interval and being separated by periods of fault quiescence.

[5] J. E. Spurr, "The Relation of Ore Deposition to Faulting," ECON. GEOL., vol. 11, pp. 601–622, 1916.

[6] H. F. Reid, "The Elastic Rebound Theory of Earthquakes," Calif. Univ. Pub., Dept. Geol. Bull., vol. 6, pp. 413–444, 1911.

The movements of pre-mineral age result in the development of both faults and vein fissures. The former are produced where excessive movement, or compression normal to the fault, or both, result in a tight fissure filled with inert and impermeable gouge. The latter are formed where small movements, or lack of compression normal to the fissure results in a minimum of gouge with a consequent open and permeable fissure. The distinction between faults and vein fissures is one of degree only, all gradations between the two being found. Veins commonly pass along their strike into unmineralized faults.

The intermineralization movements, those fault movements which continuously recur throughout the period of mineralization, affect both the faults and the vein fissures. Where the gouge-lined faults are affected, the plastic gouge is deformed and squeezed, thereby perpetuating itself. The growing veins, once they have started to form, are fairly immune from the later development of gouge. The early vein matter, on being affected by the recurrent intermineralization fault movements, is brecciated, forming a porous, permeable mass of crushed quartz which is later recemented by the mineralizing solutions. This action may recur innumerable times during the mineralization, and may result either from movements along the vein fissure, or locally from movements along the cross-faults.

Post-mineral continuance of the fault movements is of importance only in that they may cause further displacements of the veins along the cross-faults, shear along the veins, or brecciation of the previously deposited vein matter. Post-mineral movements may to some extent mask the evidence of the intermineralization fault activity.

THE MECHANICS OF VEIN FORMATION.

The extreme importance of pre-mineral and intermineral faulting in connection with mineralization must be manifest. Pre-mineral faulting is important in that it is these movements which develop the vein fissures. Intermineral faulting is of equal importance in that the features of the vein fissures are continuously

undergoing modification thereby during the time of the mineralization.

Taber has considered in detail the mechanics of the various processes whereby veins may be formed.[7] Although he postulates six possible modes of origin, a study of his paper reveals that only three mechanical processes of vein formation are involved, each of these three being subdivided into two cases dependent on whether the mineralizing solutions were ascending in the fissure or entered the fissure by lateral secretion. The three possibilities recognized by Taber for vein formation are:

(1) Vein growth by replacement of the adjacent wall rocks.
(2) Deposition in an open fissure.
(3) Deposition in openings produced by the force of crystallization of the growing vein minerals.

For the sake of completeness, two other theories of vein formation which were not considered by Taber must be mentioned. These are:

(4) Deposition in openings produced by the hydrostatic pressure of the mineralizing solutions.
(5) Veindike injection, following Spurr.

Although any or all of these processes of vein formation may be feasible and locally applicable, another mode of vein formation exists which available evidence indicates is universally important, namely:

(6) Vein formation by the repeated filling of small openings produced recurrently by intermineralization fault movements.

For this mode of vein formation the writer has proposed the term *vein formation by accretion.* This process is pictured as the alternate brecciation of previously deposited vein matter followed by recementation and filling of the open spaces. Such brecciation and recementation may be repeated innumerable times during the formation of a vein. By this process veins of any width could

[7] S. Taber, "Mechanics of Vein Formation," *A. I. M. E. Trans.*, vol. 61, pp. 3–41, 1920.

be built up without essential replacement of the adjacent wall rocks having occurred, or without vein fissures open to a width comparable to the width of known veins ever having existed.

The process is as applicable under deep-seated conditions as under shallow conditions, since the openings existing at any one

FIG. 1. Early barren vein quartz, brecciated by intermineralization fault movements and recemented by late quartz and sulphides. Alaska Gastineau Mine. ¾ natural size.

time would be trivial. The only essential condition is numerous fault movements of small magnitude occurring contemporaneously with the mineralization—exactly those movements postulated by the Elastic Rebound Theory.

That vein formation by accretion is the dominant method of vein formation is supported by abundant and varied evidence. Figs. 1 and 2 offer visual proof of the presence in vein ores, shallow and deep, of intermineralization brecciation. These specimens are characteristic and were selected only to the extent that they show evidence of brecciation sufficiently clearly for illustrative purposes.

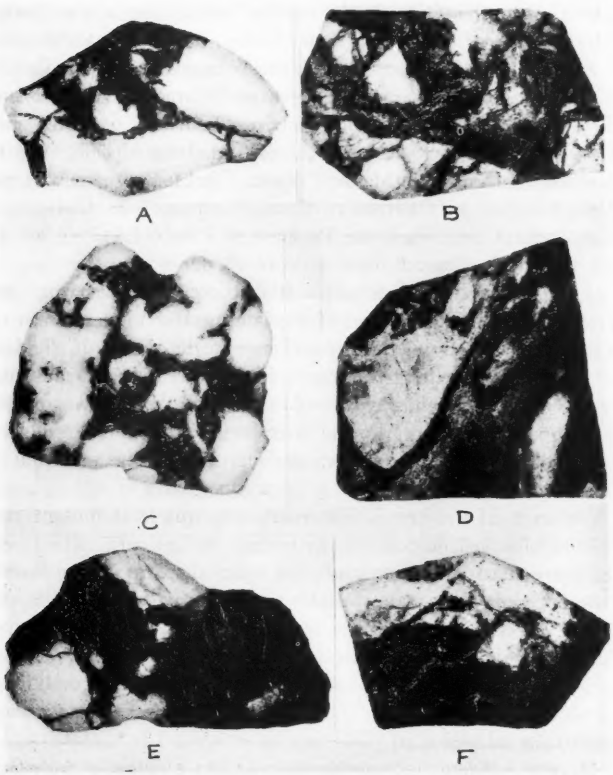


FIG. 2. Early barren vein quartz, brecciated by intermineralization fault movements and recemented by late quartz and sulphides. *A*. Providence Mine, Grass Valley, Cal.; *B*. California Rand Silver Mine, Randsburg; *C*. I X L Mine, Silver Mountain Dist., Cal.; *D*. Santa Rosalia Mine, Parral, Chih., Mex.; *E*. Cerro Gordo Mine, Inyo County, Cal.; *F*. Santa Margarita Mine, Pachuca, Hgo., Mex. Polished surfaces. Natural size.

Positive evidence of intermineralization brecciation has been identified by the writer in the ores of various deposits at Butte; Mother Lode of California; Grass Valley; Randsburg, California; La Natividad Mine, Oaxaca, Mexico; Tonopah; Goldfield; Parral, Chihuahua, Mexico; Silverton region of Colorado; Premier Mine, British Columbia; Porcupine District, Ontario; Coeur d'Alene; Gold Circle District, Nevada; Alaska Juneau gold belt; Austin, Nevada; Silver City, Idaho; Cripple Creek; Bingham; Owens Valley region of California; Foothill copper belt, California; Kalgoorlie; Comstock Lode; Pachuca; and the quicksilver belt of the California Coast Ranges.

Evidence of the intermineralization brecciation occurring just previous to the introduction of the late metallic minerals is usually the most apparent. Here a change in the nature of the materials being deposited before and after the brecciation lends contrast. Even here, however, replacement of the borders of the early quartz fragments by the later metallic minerals results in rounded and irregular outlines and borders, with a consequent masking of the evidence.

Evidence of the brecciation where only quartz is present can only be observed microscopically in thin section. In some cases the quartz deposited before and after a period of brecciation shows different grain sizes and orientation, so that the effect may be observed under crossed nicols. This effect, however, is only produced where a sufficient time elapses between the deposition of the earlier and the later quartz so that a distinct change in conditions of deposition occurs (*e.g.*, change in temperature and concentration of the solutions).

More commonly the later quartz continues to grow with the same orientation as the earlier quartz of the fragments, with the result that evidence of brecciation cannot be seen under crossed nicols. Frequently in such cases, however, the earlier quartz is more cloudy than the later quartz so that by plane light the cloudy angular fragments of the early quartz can be seen surrounded by clear younger quartz. These patches or veinlets of clear younger quartz are termed " phantom veinlets " and have been previously

described by Adams as being common in the gold ores of the Mother Lode of California.[8] The presence of similar veinlets in quartz vein-matter was also noted by Taber.[9]

All degrees of contrast in cloudiness between the older fragments and the younger phantom veinlets are to be observed in ores. Phantom veinlets may frequently be found which can only just be differentiated from the adjacent fragments. By inference, if the deposition of material before and after a period of brecciation is separated by such a short interval that the solutions and physical conditions have not had time to change appreciably, the younger quartz would be identical with the older quartz, and growing onto the older fragments with optical continuity, no evidence whatever of the brecciation would exist. It must be recognized therefore that intermineralization brecciation may be even more abundant than is called for by the known evidence.

Microscopic evidence of intermineral brecciation, including photographs of phantom veinlets, is offered in Fig. 3.

The presence of early intermineralization brecciation of the quartz gangue is usually not apparent in the polished surface by using the ordinary methods with vertically incident illumination, although the effects of the brecciation which just precedes the introduction of the metallic minerals can commonly be seen by using these methods. By using inclined illumination, however, or preferably, using vertical illumination with crossed nicols, the internal structure of the quartz becomes manifest and quite frequently fragments of cloudy quartz can be seen set in a matrix of younger clearer quartz.

The presence of fragments of wall rocks imbedded in veins has attracted considerable attention in recent years, and has been accounted for by replacement; as the result of loose rubble filling the vein fissure previous to the mineralization; as the result of fragments pried from the vein walls by the force of crystallization of the growing vein minerals; and by suspension in a viscous ore magma. The process of vein formation by accretion not only

[8] S. F. Adams, "A Microscopic Study of Vein Quartz," Econ. Geol., vol. 15, pp. 623–664, 1920.

[9] S. Taber, *op. cit.*, p. 17.

FIG. 3. Microscopic evidence of intermineralization fracturing and brecciation. *A*. Sylvanite cementing brecciated early barren quartz. Cripple Creek. *B*. Early chalcedonic vein-matter, brecciated and recemented by later quartz. Metallic minerals introduced with the late quartz. Gold Circle District, Nevada. *C*. Early barren clear quartz, brecciated and recemented by late quartz and accompanying sulphides. Four periods of brecciation are shown in the slide from which this photograph was taken, the sulphides being introduced following the third brecciation. Prieta Vein, Parral, Chih., Mexico. *D*. Gold and galena introduced along fractures and replacing adjacent older quartz. Note phantom veinlets and evidence of brecciation throughout the quartz. Central Eureka Mine, California. *E*. Phantom veinlets of clear young quartz cutting cloudy older quartz. The sulphides are invariably associated with the clear younger quartz. Sunnyside Mine, San Juan County, Colorado. *F*. Phantom veinlets of clear young quartz cutting older cloudy quartz. The sulphides are associated with the young quartz and to some extent fill fractures cutting the young quartz. Central Eureka Mine, California. *A*. Polished surface $\times$ 50; all others thin sections, ordinary light, $\times$ 15.

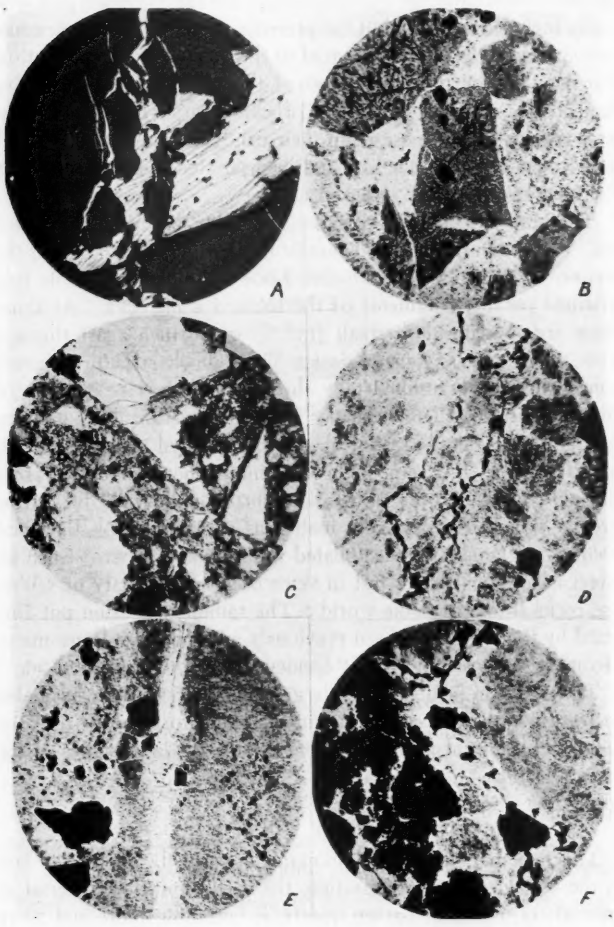


FIG. 3.

offers a more satisfactory explanation for the fragments of wall rocks included in veins, but the presence of such fragments would be expected to be almost essential to this mode of vein formation. During the recurrent reopenings of the vein it would invariably happen that portions of the wall rock which were frozen to the vein would be torn loose from their original positions in the wall and would be surrounded by and incorporated in the vein during the later stages of the mineralization.

The Mother Lode of California, occurring as it does in foliated wall rocks, offers the best example of this process known to the writer. Portions of the Mother Lode contain innumerable thin oriented parallel fragments of the foliated wall rocks. At times these are spaced only a small fraction of an inch apart through vein thicknesses of several feet. This "book structure" could conceivably have resulted only through countless reopenings of the vein fissure contemporaneous with the mineralization, each reopening tearing loose a thin film of the foliated wall rock which had frozen to the vein. The reopenings here commonly tore through the wall rocks rather than through the vein due to the greater strength of the vein matter as compared with the bond holding the lamella of the foliated wall rocks together. Such an effect is commonly manifest in veins occurring in slaty or schistose rocks throughout the world. The same explanation put forward by the writer has been previously advocated by Ransome to account for the origin of the "banded ore" of the Mother Lode.[10]

The writer in field work, underground, has repeatedly been able to trace out the process of fragments being torn loose from the walls and being incorporated in the vein by the later stages of the mineralization.

THE SEQUENCE OF MINERALIZATION.

The fact that the metallic minerals are usually introduced late in the sequence of mineralization, the early-deposited material in general consisting of barren quartz, is becoming more and more clearly recognized by students of ore deposits. In spite of this,

[10] F. L. Ransome, U. S. G. S. Geologic Folio No. 63. Mother Lode District, California, p. 7, 1900.

however, the possible bearing that the late introduction of the ore minerals may have on the formation of ore shoots has so far received no consideration.

In order to give a more detailed picture of the succession of events the following diagrams typical of the sequence of mineralization in three distinct types of ore deposits are presented. These diagrams are designed for qualitative use only. They represent the composite results of studies of numerous thin sections and polished surfaces, combined with field work.

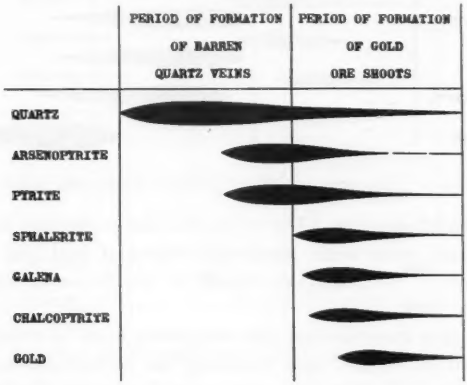


FIG. 4. Sequence of Mineralization—Mother Lode Gold Veins.

The first diagram (Fig. 4) pictures the relative time of introduction of the more common minerals of the mesothermal gold veins as exemplified by the Mother Lode of California. The width of the lines represents in a roughly qualitative manner the relative amounts of each mineral deposited from time to time during the mineralization. Comparison between lines is limited to the time relation only, the widths of the several lines in no sense indicating the relative abundance of the different minerals.

A consideration of the time relations involved in Fig. 4 for the mesothermal gold ores indicates clearly that those veins or portions of veins receiving only the early quartzose mineralization are of

necessity barren, while ore shoots can result only where the vein fissure receives deposition of minerals during the later stages of the mineralization.

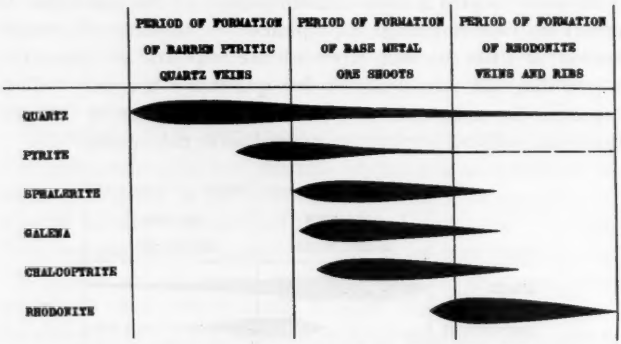


FIG. 5. Sequence of Mineralization—Sunnyside Mine.

The second diagram (Fig 5) is for the epithermal to mesothermal base metal veins, particularly those of lead and zinc, as exemplified by the Sunnyside deposit of the Silverton region of Colorado.

Here again it is manifest that ore shoots must be restricted to those portions of the veins receiving the mineralization of the second stage. Portions of veins receiving mineralization only during the first stage will consist of barren quartz, whereas those portions of the veins formed during the third stage consist essentially of barren rhodonite.

The third diagram (Fig. 6) is typical of the epithermal precious metal deposits, the example here represented being the sequence of mineralization of the California Rand Silver deposit of Randsburg, California. Although the mineralization of the epithermal deposits is usually more complex than is that of deeper-seated types, the same commonplace stages of early barren siliceous gangue and late metallization are characteristic.

Here once more the stage of formation of barren veins is contrasted with the stage of formation of the ore shoots in a clear-cut manner.

Although an early stage of barren quartz coupled with a late stage of metallization is characteristic of the majority of vein deposits, exceptions to this commonplace sequence are not unknown, though they appear to be rare.

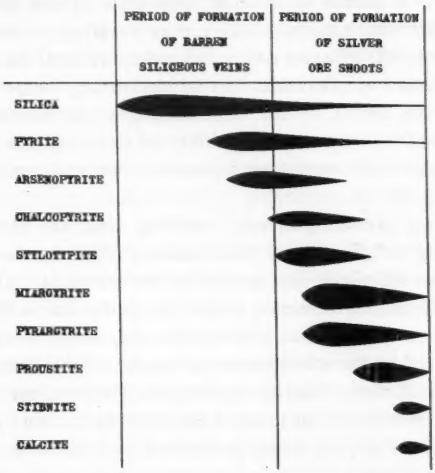


FIG. 6. Sequence of Mineralization—California Rand Silver Mine.

The more common of the known exceptions are represented by one of two conditions, as follows: The ore minerals are introduced contemporaneously with the bulk of the quartz of the deposit; or quartz is largely absent, the bulk of the introduced material consisting of metallic minerals and associated carbonates. In either of these cases, the thesis of this paper must be modified, in general to the effect that the ore, if such be developed, is more or less coextensive with the material introduced. In deposits possessing these latter characteristics, the ore shoots essentially correspond to the "shoots of occurrence" as recognized by Irving.[11]

[11] J. D. Irving, "The Localization of Values or Occurrence of Shoots in Metalliferous Deposits," ECON. GEOL., vol. 3, pp. 143–154, 1908.

THE ZONAL THEORY.

Open space for the passage of mineralizing solutions and for the deposition of ore being available, deposition can take place provided the physical-chemical conditions are favorable. The chief factors which permit or prohibit deposition by the mineralizing solutions are temperature, pressure, concentration of the solutions, and the chemical behavior of the individual mineral compounds.

Temperature is important in that decreasing temperature, the result of the ascent of the mineralizing solutions towards the surface, results in decreased solubility of the materials carried by the solutions, with consequent supersaturation and resultant deposition.

Decreasing pressure, likewise resulting from the ascent of the mineralizing solutions, may have a direct effect on the solubility of the mineral constituents carried by the solutions. Of perhaps greater importance, however, is the possibility that with decreasing pressure a critical point or points occur at which volatile constituents carried by the solutions are no longer soluble therein. The elimination of these volatile constituents (mineralizers) may so affect the solubility of the mineral constituents carried by the solutions that the dumping action postulated by Spurr [12] may well be expected to occur.

Concentration of the mineral constituents carried by the solutions must have a direct bearing on possible deposition at any given place. Where the concentration closely approaches the point of saturation of the solutions, slight decreases in temperature and pressure may sufficiently lower the point of saturation that deposition will result. Where, however, the original concentration of the mineral constituents is low, considerable drops in temperature and pressure may be necessary before supersaturation and the consequent deposition of minerals will occur.

The chemical behavior of the individual mineral compounds, in its bearing on ore deposition, has not received adequate study. Certain minerals, which have been termed " persistent," are found

[12] J. E. Spurr, "The Camp Bird Compound Veindike," Econ. Geol., vol. 20, pp. 115–152, 1925.

deposited throughout all depth zones, as for example quartz and chalcopyrite and pyrite. Their deposition through the widely varying conditions of temperature and pressure of the several depth zones is certainly suggestive that the point of saturation of the constituents of such minerals changes gradually with decreasing temperature and pressure. In consequence deposition of small amounts of these minerals through a considerable vertical range would keep the concentration adjusted to the point of saturation, both gradually decreasing.

Certain other minerals which are commonly termed "typomorphic," such as cinnabar and the sulpho-salts of silver, are only deposited within closely limited conditions of temperature and pressure. While the possible "dumping action" previously referred to may in part account for this condition, it is suggested that the zonal limitations of deposition shown by such minerals may in part at least result from a sudden lowering of the saturation point of the constituents of these minerals in solution at some critical combination of pressure and temperature.

While the tendencies of the various factors involved in the zonal theory are receiving more and more attention, it must be admitted that the quantitative aspect of these several factors of temperature, pressure, concentration, and chemical behavior offers an almost virgin field of study.

THE MECHANICS OF ORE-SHOOT FORMATION.

If the preceding evidence and discussion of this paper be accepted, it must follow that the deposition of minerals in an ore deposit, and the nature of the materials deposited, following the zonal theory, are functions of the control of temperature, pressure, concentration and chemical behavior of the individual minerals.[18]

Similarly the locus of deposition is a function of local vein structure, faulting contemporaneous with the mineralization, and the sequence of mineralization.

If the sequence of mineralization is such that the valuable minerals are introduced early or throughout the period of mineraliza-

[18] The nature of the materials deposited would also be a function of the metals available from the source-magma, *i.e.*, of the metallogenic province.

tion, the ore shoots will be "shoots of occurrence" and will be more or less co-extensive with the vein filling. This condition is occasionally encountered in deposits of any of the metals, but is characteristic only of deposits of tin and tungsten. Minerals of tin and tungsten and certain associated elements, are commonly introduced more or less contemporaneously with the bulk of the quartz, so that "shoots of occurrence" of these metals are rather characteristic.

For most of the metals, however, including gold, silver, copper, lead, zinc and quicksilver, a late time of introduction prevails. For most deposits containing these metals, therefore, definite ore shoots occur which are not co-extensive with, but form only a small part of the total vein filling. The loci of deposition of these ore shoots are due strictly to mechanical control. The shoots form at those structural positions where intermineralization fault movements produce reopenings of the vein fissure at a time immediately preceding and during the metallization.

Arguments in favor of the process of vein formation by accretion have been put forward. The formation of ore shoots follows this same mechanical process of accretion, the locus of ore deposition during the time of metallization being in general repeatedly reopened and brecciated, ore minerals being continuously deposited in the open spaces so produced.

It must be clearly recognized that all favorable structural positions will not be affected by fault movements during the period of metallization and hence will have no contained or related ore shoots. Certain favorable structural positions may suffer reopenings too early or too late to catch the valuable metallization.

The writer has studied many cases of favorable structural positions in veins where repeated reopenings had occurred during the early stage of the mineralization, resulting in large "blow-outs" of barren quartz, but where cessation of the fault movements previous to the advent of the metallizing solutions resulted adversely to the development of ore. In a few such cases slight fissuring during the time of the metallization resulted in the barren quartz of the "blow-outs" being intersected by a few random

veinlets rich in sulphides, showing clearly that had the principal reopenings occurred later with respect to the sequence of mineralization a valuable orebody would have resulted.[14]

Occasionally a favorable structural position, even though suffering brecciation at the proper time, will not be so situated that it will be subjected to the action of the metallizing solutions. A few cases have been observed where favorable positions which had been brecciated at the proper time were apparently inaccessible to the metallizing solutions due to isolated positions in the vein and to the presence of impermeable fault gouge in adjacent portions of the vein fissure.

It does not appear feasible to predict in advance of actual exploration whether a given favorable position on a vein has or has not been affected by the requisite fault movements at a time contemporaneous with the metallization.

It is feasible in many cases however to predict positions along a vein where favorable structure may be expected to occur. Manifestly if the position occupied by favorable structure can be predicted in advance of actual exploration, the exploration of that portion of the vein is fully justified. It is of extreme importance therefore to recognize and classify those vein structures which are favorable for the development of ore shoots if acted upon by fault movements at the proper time during the period of metallization.

STRUCTURES FAVORABLE FOR THE DEVELOPMENT OF ORE SHOOTS.

Since the amount of brecciation and reopening required for the development of a base metal ore shoot is considerable, the structures on which base metal ore shoots are dependent are usually quite apparent.

For the precious metal ore shoots, however, the required amount of brecciation and reopening of the vein may be trivial and result from very slight variations in the vein structure. In consequence the structural control of many precious metal ore shoots can be deciphered only with the greatest difficulty, and then many

[14] The writer hopes at another time to describe in detail certain of the illustrative cases studied, which lack of space prohibits here.

times only because of familiarity with ore shoots of base metal deposits controlled by similar but more pronounced structures.

It must be clearly borne in mind that the following structures are effective only when acted upon repeatedly by slight fault movements during the time of metallization.

1. *Variation in Strike of Vein.*—Local variation in strike of a vein fissure, coupled with shear along the fissure, provides an effective locus of deposition for an ore shoot. The mechanics of the control are shown in plan in Fig. 7.

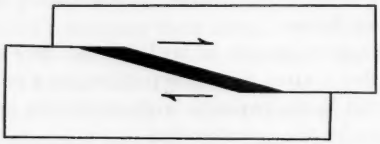


FIG. 7. Mechanics of control of location of ore shoot by variation in strike of the vein fissure.

The magnitude of the reopening produced by this type of structure will be a function of both the variation in strike and the amount of shear.

Where base metal ore shoots are controlled by this type of structure the variation in strike is usually sufficiently pronounced as to be quite noticeable. For the development of precious metal ore shoots however a local variation in strike of the vein fissure of only a degree or so may be a sufficient control. In such cases the variation may be so small and inconspicuous as to practically defy detection.

Several examples of ore shoots controlled by local variation in strike of the vein fissure are known to the writer. One of the clearest cases is the ore shoot of the Arevalo Mine near Pachuca, Mexico, shown in Fig. 8. This ore shoot is the only shoot of importance occurring along the Arevalo fault and it occupies the only position of local change in strike of the fault which is known within a distance of several kilometers in either direction.

At the Sunnyside Mine in the Silverton district of Colorado, two of the most important ore shoots which have been developed

are controlled by variation in strike of the vein fissure (Fig. 8, *B*). Minor pre-mineral cross-faults modify these ore shoots to some extent.

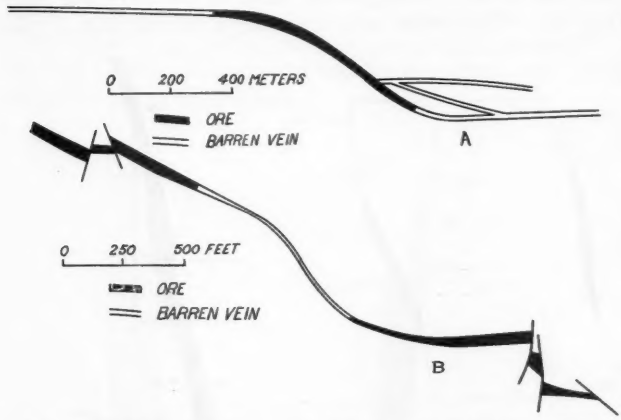


FIG. 8. *A*, Control of location of ore shoot by variation in strike of vein fissure. Arevalo Mine, Pachuca, Mexico. *B*, Ore shoots controlled by variation in strike of the vein fissure coupled with intermineralization cross-faults. Sunnyside Mine, Colo.

The Camp Bird Vein in the same region has been described as containing a series of ore shoots which all occupy positions of local variation in strike of the vein fissure.[15]

2. *Variation in Dip of the Vein.*—Variation in dip of the vein fissure, coupled with a vertical component of shear, may act independently in providing a favorable site for ore deposition; or it may act in conjunction with and modify the effects of variation in strike.

Two cases must be recognized, dependent on whether the vertical component of faulting is normal or reverse. If normal the steeper portions of the fissure are the more favorable, whereas if the movements are of a reverse nature the reopenings are more

[15] J. E. Spurr, *op. cit.*

pronounced in the flatter portions of the vein fissure. These conditions are illustrated in Fig. 9.

The effects of variation in dip on ore deposition are beautifully illustrated in the Washington ore shoot of the Sunnyside Mine (Fig. 10). This shoot, occurring along a normal fault, is controlled primarily by variation in strike of the vein fissure. Within the shoot, however, variations in dip occur, the steeper portions of the shoot being both thicker and richer than the flatter portions.

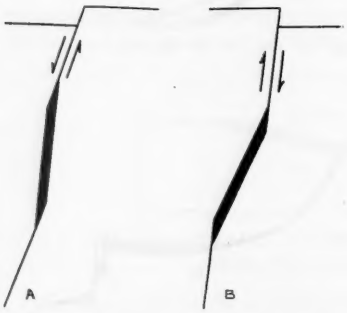


FIG. 9 (left). Mechanics of control of location of ore shoot by variation in dip of the vein fissure. *A*, In a normal fault the steeper portions of the vein are the more favorable. *B*, In a reverse fault the flatter portions of the vein are the more favorable.

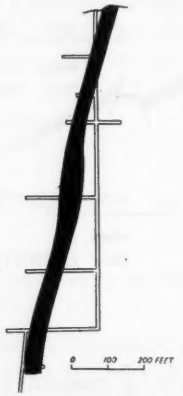


FIG. 10 (right). Modification of ore shoot by variation in dip. The steeper portions of the vein are wider and richer. The vein fissure is known to be a normal fault. Washington Vein, Sunnyside Mine, Colorado.

Purington has recorded that in a number of instances at the Virginius and Smuggler Mines in the same region, the veins widen or swell on the steep dips and pinch where the dip is flatter.[16]

[16] C. W. Purington, U. S. G. S. Geologic Folio No. 57, Telluride Quadrangle, Colorado, p. 16, 1899.

3. *Intersection of Veins and Cross-Faults.*—The portions of veins in the vicinity of intersections with cross-faults are commonly favorable positions for ore-shoot formation, but only where the cross-faults have suffered intermineralization movements. Such movements on the cross-faults brecciate the previously deposited material of the vein, providing the necessary reopenings for the passage of the metallizing solutions and for the deposition of the ore minerals.

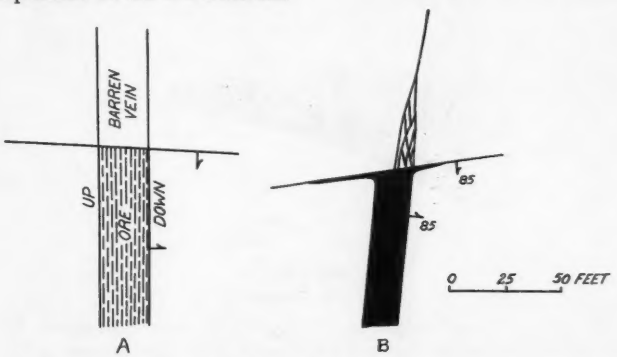


FIG. 11. *A*, Termination of ore shoot by an intermineralization cross-fault. North of the fault the early barren vein remained tight; south of the fault intermineralization movements caused brecciation with the resultant development of an ore shoot. Purisima Vein, Pachuca, Mexico. *B*, Termination of ore shoot by a pre-mineral cross-fault. North of the fault only a small stringer system exists. Santa Inez Vein, Pachuca, Mexico.

The cross-faults responsible for ore-shoot formation may be pronounced lines of movement, or in some cases they may be merely minor joint planes. The amount of movement which occurs thereon may vary within considerable limits. In general base metal ore shoots require considerably more brecciation and reopenings for their formation than do precious metal ore shoots, the latter at times developing where only a very minor amount of brecciation has occurred.

The ore shoots may develop in the immediate vicinity of the cross-fault; or the shoots may extend for some distance along the vein, being terminated at the cross-fault. In the former case the vein has been brecciated only in the immediate vicinity of the cross-fault by intermineralization displacements thereon; whereas in the latter case movements along the vein (commonly a settling of the hanging wall) have been taken up along the cross-fault, with the result that the vein on one side of the cross-fault is brec-

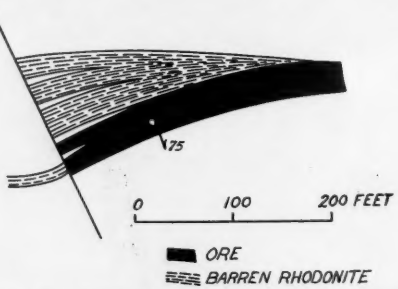


FIG. 12. Ore-shoot control by an intermineralization cross-fault. To the east, gapping of the vein fissure against the cross-fault resulted in the development of an ore shoot; continued gapping caused the formation of a large bunch of post-metallization barren rhodonite. West of the fault only a small stringer system was developed. Sunnyside Mine, Colo.

ciated and reopened while on the opposite side of the fault the vein remains tight and impervious to the metallizing solutions. Examples of ore-shoot control by cross-faults are shown in Figs. 11 and 12.

Where intermineralization displacements occur on the cross-fault, the vein fissure may be "stretched open" and receive ore deposition on one side only of the cross-fault as is shown in Fig. 12, or the "stretching" action may cause reopenings of the vein on both sides of the crossing as is illustrated in Fig. 13.

Ore-shoot control by the "Indicator Veins" of Australia undoubtedly represents an example of this type of structural control. The "Indicator Veins," which produce ore shoots where

they intersect the main veins and reefs, have been variously described as thin quartz seams, themselves auriferous; as thin chloritic bands; thin seams of pyrite; thin beds of black carbonaceous slate containing much pyrite; thin zones of fault gouge; bedded structures; secondary structures crossing the bedding planes; and faults and small fissures.[17]

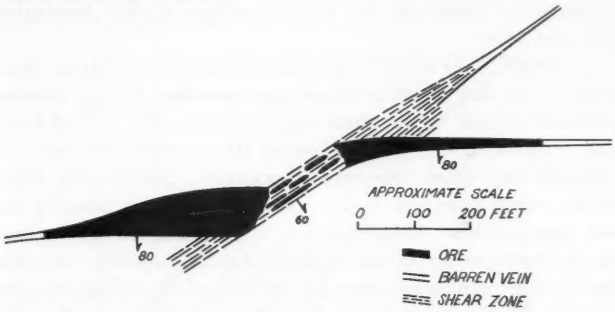


FIG. 13. Control of ore shoot by "stretching action" along a cross-zone of intermineralization fissuring. Prieta Mine, Parral, Mexico. Sketch map made on surface, approximate only.

Although precipitating or catalytic action by the material contained in the "Indicator Veins" has been the popular explanation for their favorable action, it must be clearly recognized that the only feature possessed in common by the various "Indicators" is that they are all planes of movement.

4. *Vein Intersections.*—It has long been recognized that ore shoots commonly occur at vein intersections, although by no means all vein intersections contain ore shoots. A vein intersection must be recognized as being a position of weakness, since intermineralization fault movements along either vein fissure will tend to produce brecciation at this position. A vein intersection therefore is at least twice as favorable a position for possible ore-shoot formation as any other random position on either vein.

[17] T. A. Rickard, "The Indicator Vein, Ballarat, Australia," *A. I. M. E. Trans.*, vol. 30, pp. 1004–1019, 1900. N. R. Junner, "The Geology of the Gold Occurrences of Victoria, Australia," ECON. GEOL., vol. 16, pp. 79–123, 1921, and others.

Ore shoots may be confined to the vicinity of the vein intersection, being controlled thereby, or they may extend for a considerable distance along one or both veins, being terminated at the intersection. The explanation is the same as for the case of intersection of a vein and cross-faults.

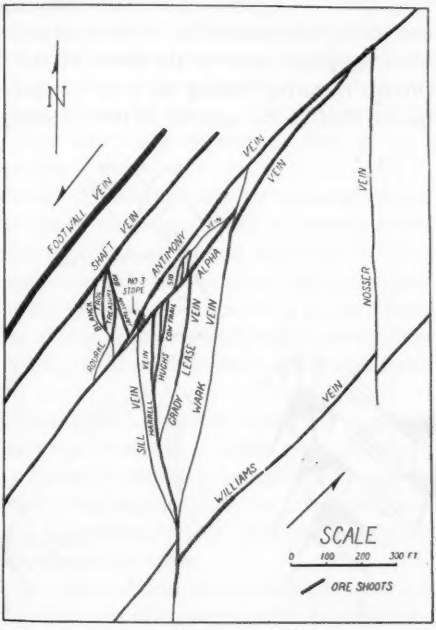
The occurrence of ore shoots at vein intersections has been recognized so commonly that it is unnecessary to offer descriptive examples here.

5. *Simple Shear along Vein.*—Simple intermineralization shear along a vein may result in reopenings unassisted by any definite structural control. Such shear may produce a thin zone of brecciation following one wall; following the center of the vein; or following any other intermediate position. Occasionally these streaks switch from side to side, occupying first one plane in the vein, then another. Metallization of these brecciated layers gives rise to important ore shoots in precious metal deposits. In such deposits the common tendency for the bulk of the values to occur in one or two thin layers or streaks in the vein, the rest of the vein being low grade or barren, has long been recognized.

In base metal deposits, however, the reopenings produced by simple shear are seldom of sufficient size to permit of the formation of workable ore shoots. The writer has examined numerous base metal veins in the San Juan region of Colorado where the effects of simple shear followed by metallization were quite manifest. The result is a streak of rich sulphides an inch or a few inches wide following the center or wall of an otherwise barren quartz vein. The effect produced, due to the quartz accompanying the sulphides and to replacement by the sulphides of the borders of the adjoining early barren quartz, is not unlike depositional banding, with which it should not be confused.

6. *Torsion Structures.*—Where a fissure is subjected to a torsional stress diagonal to its strike, it tends to gap open, producing a place favorable for ore deposition. It sometimes happens that two or more parallel fissures which are being subjected to horizontal shearing stress are sealed by the early barren quartz stage of the mineralization. Continuance of the shearing stress then

may find the initial fissure lines tightly sealed and stronger than the adjacent wall rocks, in which case the stress may be relieved by the development of new torsion fractures diagonal to the direction of the stress and to the original fissures. These torsion fractures, escaping the early barren stage of the mineralization, and coming into existence about the time of the metallization, are ideal for ore deposition.


N
FOOTWALL VEIN
SHAFT VEIN
NO. 3 STOPE
ANTIMONY
ALPHA
VEIN
VEIN
VEIN
NOSSER
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VEIN

major lines of shear which were tightly sealed by the early stage of barren quartz and chalcedony. The later stresses were relieved by the development of northward-striking torsion fractures which received the bulk of the metallization. The northeast veins were metallized only where brecciated by the later stresses.

7. *Saddle, Trough and Leg Reefs.*—When a series of sedimentary strata are compressed into alternate anticlines and synclines, openings *tend* to be produced beneath competent beds on the anticlines, above competent beds in the synclines, and shear occurs between competent beds on the limbs of the fold (Fig. 15, *A*). Ordinarily during folding the incipient openings which *tend* to form are filled by the material of the less competent beds

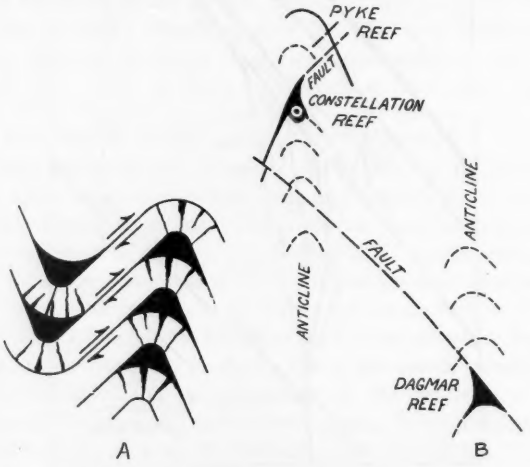

FIG. 15. *A*, Mechanics of formation of saddle reefs, trough reefs, and leg reefs. Leg reefs tend to develop at positions of shear between competent members, while saddle and trough reefs form where incipient reopenings occur as the result of arching of the competent beds. The black indicates localities where reopenings *tend* to occur as the result of folding. *B*, Relation of saddle reefs to faulting. Bendigo, Australia. After Stillwell.

as the result of internal deformation of these beds—thinning on the flanks of the folds and thickening in the arches and troughs.

If the region is undergoing mineralization, however, the incipient openings which *tend* to form may be filled by the products of mineralization. Thus through the repeated production of small openings by the folding and the contemporaneous filling of the openings by the products of mineralization, a saddle reef may conceivably be formed by the process of accretion with little or no replacement being required. That such may be true is attested by the evidence of brecciation present in saddle reefs.[18]

Saddle reefs are most characteristically developed in low plunging folds, but not necessarily so. Ore bodies may occur in the arches of folds which are standing on end, as for example at Jerome, Arizona.[19]

The ore shoots of saddle reefs are characteristically related to intersecting faults (Fig. 15, *B*) or to certain intersecting beds. While chemical control of the ore deposition resultant from the nature of such beds has been the usual explanation put forward to account for the associated ore shoots, it appears probable, and is supported by descriptions, that such beds mark the lines of bedding faults or planes of shear, the shear being consequent upon the folding.

This association with planes of movement is entirely suggestive therefore that the ore shoots of saddle reefs, like those of vein deposits, have formed through the process of accretion, the locus of ore deposition being dependent on the brecciation and reopenings produced by intermineralization faulting—*i.e.*, by the shear resulting from the compression.

8. *Mineral Pipes.*—Locke has recently identified in certain mineral pipes another type of structure which is favorable for the formation of ore shoots.[20] In this type of structure a block of

[18] F. L. Stillwell, "The Factors Influencing Gold Deposition in the Bendigo Gold Field," Commonwealth of Australia, Advisory Council of Sci. and Industry, Bull. 16 (1919).

[19] J. L. Fearing, "Some Notes on the Geology of Jerome," ECON. GEOL., vol. 21, pp. 757–773, 1926.

[20] A. Locke, "The Formation of Certain Ore Bodies by Mineralization Stoping," ECON. GEOL., vol. 21, pp. 431–453, 1926.

ground subsides as the result of "mineralization stoping," or other cause, producing a cylindrical brecciated zone.[21] The subsidence (known as mineral collapse) and resultant brecciation are recognized as overlapping on the mineralization. In consequence open spaces for the passage of solutions and for the deposition of ore minerals are produced after much of the early barren quartz has been deposited, and these open spaces are still available at the time of the late metallization.

The ore shoots formed in this type of structure are strictly dependent for their location on the open spaces formed by the intermineralization movements and which are existent at the time of the metallization.

9. *Miscellaneous Structures.*—Among the minor types of structure which may be favorable for ore deposition may be mentioned *unfilled vein centers.* Where the early barren quartz stage of the mineralization has not been intensive, the initial fissure may remain incompletely filled at the time of the metallization. In such cases ore shoots may be formed which are coextensive with such openings as still existed at the time of the metallization. Such ore shoots differ from shoots of occurrence insofar as the narrower portions of the fissure may have been completely filled by barren gangue, only the wider portions of the vein still remaining open and receiving ore during the time of the metallization.

While it is felt that the more commonplace types of structure on which ore shoot formation is dependent have been identified, undoubtedly a few types of structure have escaped notice and have yet to be described.[22] Possibly of chief interest among the structures which have not been considered are those of the type repre-

[21] See Locke's Fig. 5.

[22] The deposition of ore at localities where the mineralizing solutions have been retarded or completely dammed is considered by the writer to result from the application of a distinct physical-chemical principle which is not directly related to the subject matter of this paper. The deposition of ore at such localities conforms to the principles of the zonal theory, however, and occurs by replacement or by the process of accretion and under the influence of intermineralization brecciation. The structures involved, in addition to favoring impedance or actual damming of the solutions, conform in their characteristics to the structures considered in this paper.

sented by the disseminated copper porphyry ores of Bingham. Whether, as is held by Locke and as seems probable, the Bingham type of structure represents a modification of the mineral pipe type of structure in which the brecciation affected the whole rock mass instead of merely the periphery of a subsiding rock plug, is not at this time certain. It is certain however that the development of ore in deposits of the Bingham porphyry type was dependent on the openings produced by intermineralization brecciation subsequent to the introduction of much of the early barren quartz, but prior to or contemporaneous with the metallization.

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SOLVENT EFFECTS OF CERTAIN ORGANIC ACIDS UPON OXIDES OF IRON.

NORMAN J. HARRAR.

INTRODUCTION.

FROM a geochemical standpoint, interest in the natural iron cycle seems to center upon the mechanism of solution. A great variety of substances present in natural waters may act as solvents upon minerals, and the effects of a number of these have been estimated from natural sources and have even been tested under artificial conditions.

Water.—It has long been known that nearly all minerals are more or less attacked by pure water. Numerous references to experiments upon this problem are recorded by Clarke.[1] Experiments with various iron compounds show that traces, at least, of this element pass into solution. Whitman, Russell and Davis[2] give the solubility of $Fe(OH)_2$ in pure water as 6.7×10^{-6} moles per liter and Almkvist[3] gives the solubility of $Fe(OH)_3$ in pure water as 0.151 mg. per liter. The solubility products[4] of these compounds are 1.64×10^{-14} for $Fe(OH)_2$ and 1.1×10^{-36} for $Fe(OH)_3$. These figures show that pure water alone is a factor in the solution of iron minerals.

Oxygen.—Water containing dissolved oxygen is capable of attacking minerals. According to Cameron,[5] "The dissolved oxygen in becoming liberated or when dissolved in the film water appears to be especially active towards the ferrous or ferro-magnesium silicates." Since the ferric forms are less soluble, the

[1] Clarke, F. W., "Data of Geochemistry," U. S. Geol. Survey (1920), p. 473.

[2] Whitman, W. G., Russell, R. F., and Davis, G. H. B., *J. Am. Chem. Soc.*, 47, 70–9 (1925).

[3] Almkvist, G., *Zeitsch. anorg. Chem.*, 1918, 103, 240–242 (*B. A.*, 1918, ii, 320).

[4] Landolt-Bornstein, "Physikalisch-Chemische Tabellen" (1923).

[5] Cameron, F. K., "The Soil Solution" (1911), p. 53.

value of the oxygen lies in its disintegration of the silicate and only indirectly in the dissolution.

Carbon Dioxide.—The solvent properties of carbonated waters were first observed and investigated many years ago. W. B. and R. E. Rogers,[6] Muller,[7] Headden,[8] and many others, and more recently J. W. Gruner[9] recorded experiments upon a wide variety of minerals. Gruner reports that water saturated with CO_2 dissolved in seven weeks, 19.1 parts per million of Fe from siderite, 28.0 p.p.m. from magnetite, and 28.9 p.p.m. from olivine —to cite but one example of the work upon this phase of the problem.

Inorganic Acids.—Many of the familiar inorganic acids are present in natural solutions, although all but a few occur in quite varied amounts and only under unusual conditions. Statements regarding the solvent effects of these acids upon iron minerals are scattered through the literature and a thorough treatment of this subject is given by Van Hise.[10]

Humic Acids.—The solvent action of organic matter, either as living plants or during the processes of decay, has long been a subject of controversy. There is no doubt, however, that some action occurs and, therefore, it has stimulated considerable work. Gruner[11] has recently conducted experiments upon the solubility of iron minerals in solutions containing decaying organic matter. He treated a number of iron minerals with circulating and static peat solutions, in the presence and absence of air, and with and without other salts. He summarizes in part, as follows:

1. Solutions from decaying plants dissolve all oxides and carbonates of iron, and most of the silicates, but do not seem to attack pyrite appreciably.

2. The strength of such solutions is similar to that of carbonic acid. It is possible that carbonic acid is the chief acid of the so-called 'natural organic acids' but the organic colloids in such solutions give special properties to them.

[6] Rogers, W. B. and R. E., *Am. Jour. Sci.*, 2d Ser., vol. 5, 1848, p. 401.
[7] Muller, R., *Jahrb. geol. Reich.*, vol. 27, *Min. Mitt.*, 1877, p. 25.
[8] Headden, W. P., *Am. Jour. Sci.*, 4th Ser., vol. 16, 1903, p. 181.
[9] Gruner, J. W., ECON. GEOL., vol. 17, No. 6, p. 407, 1922.
[10] Van Hise, C. R., "A Treatise on Metamorphism" (1904), p. 93.
[11] Gruner, J. W., *op. cit.*, p. 435.

3. One of the differences between natural organic solutions and carbonic acid is that the organic solutions reduce ferric iron compounds to soluble ferrous salts, while carbonic acid does not.

Organic Acids.—Only a few of the many references to the solvent action of organic materials upon iron minerals distinguish between that group of substances referred to as humus or humic acids and the familiar and definite organic acids.

Schreiner and Shorey [12] write,

> Hydroxy-acids of the fatty series are very widely distributed in the vegetable kingdom—(mentioning malic, citric, tartaric, glycollic, lactic, butyric, formic, acetic)—there is no doubt that vegetable acids of this group are added to soils in large quantities and become temporarily, at least, a part of the organic matter of the soil—.

E. C. Harder [13] in his important monograph describes in detail the processes producing the organic acids "—such as butyric, propionic, formic, lactic, acetic, citric, tartaric, valerianic—" and further states that, "According to the extent to which organic acids are present iron may be carried in solution as salts of these acids. It is not impossible that such organic salts as iron formate, iron butyrate, iron lactate, or iron citrate may occur in iron bearing waters."

For the other important solvent agents quantitative values seem to have been determined. A number of these experiments have been cited and records of many others appear in the literature. However, there has been little or no work done upon the effects of some of the naturally occurring organic acids upon iron minerals, as compared with the above substances and as compared with each other. The following pages report briefly a study made upon the solvent effects of some common organic acids upon some oxides of iron.

PLAN OF WORK.

Three iron oxides were selected—a pure ferrous, a pure ferric, and a hydrated oxide, a natural limonite. These should give a

[12] Schreiner, O. and Shorey, E. C., U. S. Dept. of Ag., Bur. of Soils, Bull. No. 74 (1911).

[13] Harder, E. C., "Iron Depositing Bacteria and their Geologic Relations," U. S. Geol. Survey Prof. Paper, No. 113 (1919), p. 44–47.

check upon any reducing effects of the acids, for although they might have some special action on ferric oxide, any reduction of ferrous oxide is impossible.

In order to insure an excess of iron over what any of the acids could possibly dissolve—thus more nearly imitating natural conditions—it was calculated how much of each of the oxides must be taken to furnish exactly two grams of iron and these quantities were used in all cases.

The selection of acids was difficult, for, without using too many of them, it was intended that they afford comparisons of types, of relative strengths, and of reducing powers. They should also be fairly common and occur, to some extent at least, in natural solutions. The acids employed and their dissociation constants are listed opposite the data. The familiar relations between length of chain and strength of acid and the effects of added carboxyl and hydroxyl groups are evident. Lacking any source of information upon relative reducing powers of these acids, some qualitative tests with permanganate were carried out. It would seem that the acids are oxidizable about in the order—Salicylic—Oxalic—Formic—Lactic—Citric—Tartaric—Malonic—and the others only with difficulty.

In order to simulate natural conditions, it was planned to use rather weak solutions. After trying twentieth normal acid solutions and finding that in many cases the amounts of iron dissolved were so small that accurate determinations were impossible with a uniform treatment, it was decided to use tenth normal concentrations.

MATERIALS.

For the pure iron oxides, Kahlbaum's Eisenoxydul and Eisenoxyd were used and the hydrated oxide was represented by an ordinary limonite specimen from Chester County, Pennsylvania. The latter upon analysis was found to contain 48.34 per cent. iron. Tests were also made to make sure that titanium and vanadium were not present, for these elements would interfere with the method used for determining the iron dissolved. These three

oxides then, were ground in an agate mortar and sieved through a 200-mesh copper screen.

The acids used were Kahlbaum or Eastman chemicals. The exact amounts to give tenth normal solutions were weighed out and dissolved. They were then titrated with NaOH, which was at the same time checked against a Bureau of Standards Benzoic Acid (Sample No. 39) and any small deviations corrected to a tenth normal basis. It should be noted that in the cases of benzoic and salicylic acids it was necessary, on account of their slight solubility, to use saturated solutions.

The iron was determined by titration against potassium permanganate, and since the amounts were small in some cases, this reagent was made up to about .025 N. concentration. It was prepared in the usual way and upon standardization against a Bureau of Standards Sodium Oxalate (Sample No. 40) was found to have an iron value of 1 cc. equal to .0015 grams Fe.

METHOD.

After some preliminary experiments the following procedure was adopted:

Everything was done to maintain uniform treatment, to insure, if nothing else, a safe basis for drawing comparisons. The usual precautions regarding calibration of apparatus were observed.

Quantities of the oxides calculated to contain exactly 2 grams of iron were placed in 500 cc. glass-stoppered bottles and these were then filled with the tenth normal acid solutions.

The bottles were shaken daily and were at an average temperature of 25° C. At 40 days and at 60 days the solutions were poured through a filter into a 200 cc. measuring flask.

Since some of the acids would, if present later, affect the permanganate reagent, these were completely charred. Finally, in every case a sulfuric acid solution was run through a Jones Reductor and titrated with permanganate. Blanks were carried along and such small corrections as were necessary were made.

It was not convenient, with so many tests upon the same days and involved procedures in most cases, to run checks in parallel.

However, the entire field was previously covered using twentieth normal acids and this work served much the same purpose.

DATA.

The following tables contain a record of the data obtained for the main purpose of this work—the securing of comparative values and a very general survey. The color changes are described as carefully as possible, for many of the conclusions are supported by the visible evidence.

MILLIGRAMS OF FE IN 100 CC. OF SOLUTION.

Acids and K. 10^{-4}.	FeO.		Fe_2O_3.		Limonite.	
	40 Days.	60 Days.	40 Days.	60 Days.	40 Days.	60 Days.
Formic 2.14.....	5.792	6.337	.951	1.249	4.329	4.352
Acetic .18.....	.520	.491	.327	.439	.505	.535
Propionic .14.....	.449	.456	.344	.374	.359	.381
Oxalic 380.00.....	42.525	12.995	97.463	36.222	6.645	3.825
Malonic 16.30.....	31.734	47.451	4.159	6.260	10.520	12.125
Succinic .66.....	.794	.973	.255	.494	1.213	1.220
Lactic 1.38.....	12.398	13.871	2.025	2.054	8.845	10.958
Tartaric 9.70.....	14.022	28.084	3.175	4.386	10.528	16.098
Citric 8.70.....	31.122	42.226	2.961	3.372	16.159	18.582
Benzoic .67.....	2.022	2.148	.428	.428	5.888	6.039
Salicylic 10.60.....	14.627	14.953	4.891	5.124	21.568	21.335
Sulfuric —.....	67.205	95.045	20.320	27.813	12.245	14.236

COLORS OF FERROUS SOLUTIONS.

When shaken—in pure water or in any of the acids—the oxide settles out rapidly—leaving a clear solution—with no visible evidence of hydrolysis.

Formic, Acetic, Propionic } No color at time of tests nor after standing 5 months.

Oxalic—in 3 days a color appears which develops into an intense yellowish green—some fading by 40 days—nearly all gone by 60 days—upon admission of air a yellowish cloudiness appears and the bottle is stained—in the checks run later these changes took place more rapidly.

Malonic—very slight green at 40 days—increasing very little thereafter.

Succinic—no color at any time.

Lactic—very slight green at 40 days—more pronounced at 60 days—becoming an intense yellowish green after 3 months.
Tartaric—slight green at 40 days—increasing to an intense green after 3 months.
Citric—green at 40 days—intense green at 60 days—changing at 90 days to yellow and deepening into amber—orange—red—dark red and remaining so thereafter.
Benzoic—no color at any time.
Salicylic—deep purple almost at once.
Sulfuric—very slight green at 40 days—increasing very little thereafter.

COLORS OF FERRIC SOLUTIONS.

When shaken—in pure water the oxide never gives a clear solution—the rate of settling in the various acids is a rough measure of their strength—in some cases these properties have been indicated.

Formic, Acetic, Propionic } No color at any time—in order listed, they are increasingly hard to filter.

Oxalic—in 3 days a yellowish green—intense at 40 days—still strong at 60 days—fading slowly and giving a cloudy yellowish suspension shortly thereafter—in the checks run later these changes took place more rapidly.
Malonic—very slight green at 60 days—increasing very little thereafter.
Succinic—no color at any time—some difficulty in filtering.
Lactic—very slight green at 40 days—slowly developing an intense yellowish green after 4 months.
Tartaric—very slight green at 40 days—slowly developing an intense green after 4 months.
Citric—slight green at 40 days—strong at 60 days—an intense green thereafter.
Benzoic—no color at any time—clear, easily filtered solution.
Salicylic—intense purple at once.
Sulfuric—very slight green at 60 days—increasing very little thereafter.

COLORS OF LIMONITE SOLUTIONS.

When shaken—in pure water the oxide never gives a clear solution—the rate of settling in the various acids is almost as slow as with ferric oxide—in some cases these properties have been indicated.

Formic—a very slight green after 60 days.
Acetic, Propionic } No color at any time—rather difficult to filter.
Oxalic—green color almost at once—intense green at 30 days—fading to a slight green at 40 days—upon admission of air a clouding occurs and at 60 days the solution has no color and is difficult to filter.

Malonic—very slight green at 40 days—increasing somewhat thereafter.
Succinic—no color at any time—some slight difficulty in filtering.
Lactic—slight green at 40 days—becoming an intense yellowish green after 3 months.
Tartaric—very slight green at 40 days—slowly developing an intense green after 3 months.
Citric—green at 40 days—strong at 60 days—an intense green thereafter.
Benzoic—no color at any time—clear, easily filtered solution.
Salicylic—very intense purple at once.
Sulfuric—very slight green at 60 days—increasing very little thereafter.

DISCUSSION.

It seems reasonable to suppose that, where conditions have been kept nearly alike for all the combinations tried, the comparative amounts of iron taken into solution will depend upon three things —the nature of the oxide—the nature of the acid—and the nature of the resulting substance. These factors will be considered briefly at this point.

Oxides.—Taken as a whole, the figures obtained seem to show that iron is most readily dissolved from the ferrous oxide, then from the limonite, and least from the ferric oxide.

In order to react with the acid the oxide must become hydrated and this process is controlled by the solubility of the resulting hydrate. Since the solubility of ferrous hydroxide is comparatively much greater than that of ferric hydroxide, as already noted, and since in limonite at least a partial hydration has already occurred, it is to be expected that the ferric oxide would appear the least soluble. The more ready removal of iron from the FeO than from limonite could hardly be predicted so surely, but the data indicate that such is the case.

Acids.—In the general equation

$$Fe(OH)_x + RCOOH \longrightarrow (RCOO)_xFe + HOH$$

the action of a particular acid must depend primarily upon the extent to which it dissociates.

The dissociation constants are included in the data table and an examination will reveal an unmistakable correlation between these

values and the amounts of iron in solution. In many cases a very definite ratio seems to exist, in most cases a comparison yields values of the same order of magnitude, and in any case the stronger acid dissolves more than a weaker one.

A possible secondary effect might result if any decomposition of an acid took place. Since iron in the ferrous state is more easily dissolved than is the ferric form—if an acid decomposed and brought about a reduction of ferric to ferrous—certainly more iron would dissolve.

Numerous statements appear in the literature upon the ability of organic acids to reduce and dissolve large quantities of iron. When such statements refer to the so-called humic acids, they are perhaps justifiable, but they certainly cannot be made regarding organic acids as a group. The problem originated upon this point.

The problem was attacked by selecting from the same series of organic compounds, acids supposed to be reducing agents and others of a very stable nature. If these acids react accordingly, then, for example, with formic acid the amount of iron dissolved from ferrous and from ferric ought to be more nearly the same as with inactive acetic acid. A number of these contrasts are possible among the acids tested.

It may be stated that reduction occurs if and when the tendency of the acid to decompose (or become oxidized) is strong enough to overcome the tendency of the iron to stay in the ferric form (to remain oxidized) and this is a question of oxidation-reduction potentials.

This phase of the problem must be left with the statement that, from a comparison of the figures for the various acids, there is, with one exception (oxalic), no positive evidence that reducing effects have played any significant part.

The Resulting Substances.—The substance that results from the action of the acid on the oxide may materially affect the reaction in one or two ways.

The solubility of the salt formed is obviously a prime factor.

This fact was kept in mind when the acids were selected and in nearly every case the salt formed was known to be at least fairly soluble, thus making a comparison of results less dependent upon this factor. The more detailed work along this line will not be described here.

The resulting substance may also affect the reaction through the formation of some sort of complex. There is certainly no lack of reference upon this subject.

It is not purposed here to discuss in detail the Theory of Co-ordination of Werner [14] nor to describe the familiar examples among iron compounds—an excellent treatment of the subject is given by U. R. Evans.[15] The work with iron-organic complexes has been done by E. Belloni,[16] R. F. Weinland and co-workers,[17] P. S. U. Pickering,[18] and a number of others.

It should be pointed out, however, that the formation of a complex of some sort means an alternate course of action, as normally

$$(RCOO)_xFe \longrightarrow (RCOO)^- + Fe^{++}$$

and in this case the production of (RCOO) ions will repress the ionization of the acid and thus lower the (H) ion concentration upon which the dissolution depends. However, if the salt

$$(RCOO)_xFe \longrightarrow [RCOOFe]$$

forms a complex in which the RCOO group is held, the reaction is no longer hindered from that source. It is quite possible that the difference this makes is a real factor, especially in the case of these weak acids.

The nature of the complexes has been the subject of much controversy, but this cannot be discussed here. Merely attempting then, to correlate the opinions of the above mentioned writers and

[14] Werner, A., *Phys. Chem.*, 14 (1894), 506 and *Ber.*, 40 (1907), 15.

[15] Evans, U. R., "Metals and Metallic Compounds," vol. 3, p. 1 (1923).

[16] Belloni, E., *Gazetta*, 1920, 50, ii, 159–212 (*B. A.*, 1920, i, 814), or *C. A.*, 1909, p. 1503, 1921, p. 839, and 1923, p. 1503.

[17] Weinland, R. F. and Loebich, O., *Z. anorg. allgem. Chem.*, 151, 27: (1926), also *C. A.*, 1918, p. 684, 1921, p. 3256, 1926, p. 1769, and 1926, p. 2127.

[18] Pickering, P. S. U., *J. Chem. Soc.*, 1913, p. 1358, 1914, p. 464, and 1916, p. 235.

to apply them to the data obtained in this study, it is possible to reach some fairly reasonable general conclusions.

Normal salts with iron in the cation are formed with acetic, propionic, succinic and benzoic acids. This is shown by the absence of color and by the characteristic hydrolysis of the first three, with the benzoate supposedly unionized.

Intense colors are developed with oxalic, lactic, tartaric, citric, and salicylic acids—indicative of a complex anion, which these are said to form with iron. It is significant that these are, with oxalic an exception perhaps, hydroxy-acids. The colors may be due to an iron-carbon linkage.

Very slight colors—usually only after long standing—develop with formic, malonic, and sulfuric acids, and in these cases the position of the iron is disputed, but the evidence indicates that most of it, at least, is in the cation.

The structure of the compounds formed must depend somewhat upon the working conditions and the above statements might not hold for different concentrations of the reagents.

The tables present several apparent inconsistencies and in those cases the usual procedure was supplemented with various other tests. Since this work may only be of indirect interest to the geologist, it shall be left with the statement that the factors already described were found to furnish sufficient explanation.

GENERAL CONCLUSIONS.

As was pointed out in the introduction, the actions of the important solvent agents have been carefully investigated—except for the organic acids. As a result of this work it is possible to make some general statements about this phase of the problem.

1. The distinction should be clearly drawn between the so-called "humic acids" and the true organic acids—the latter do not exhibit "reducing actions" and are far more effective solvents.

2. No sweeping statements can even be made about organic acids as a group—the chief factors in cases of this kind are: the nature of the oxide (ease and degree of hydration, solubility of

the hydrate); the nature of the acid (degree of dissociation, stability); the nature of the resulting substance (solubility, complex formation).

3. It was found that of the iron oxides, the ferrous dissolved most readily, limonite a little less so, and the ferric much more difficultly.

4. A definite relation was found to exist between strengths of acids and quantities of iron dissolved.

5. It is significant that the hydroxy-acids, said to form complex anions with iron, dissolved abnormal quantities and underwent striking color changes.

6. Some of these supposedly weak organic acids dissolve remarkable quantities of iron and in natural solutions would be the most effective of all solvents.

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THE IDENTITY AND GENESIS OF LODESTONE MAGNETITE.

W. H. NEWHOUSE.

LODESTONE is magnetite which possesses polarity like an ordinary magnetic needle or magnet. Mineralogists have used the term only for magnetite in which the strength of polarity is marked, but all gradations appear to exist between ordinary magnetite with little or no polarity and that in which a fragment will pick up large iron nails.

Only a very small percentage of the magnetite known in the world possesses the degree of polarity requisite for lodestone. This polarity is commonly attributed to the action of the earth's magnetic field on magnetite.

The tendency to retain "permanent magnetization" or a polar state is called remanence. The analogy with iron is most striking and instructive in this respect. The remanence is much more marked in some kinds of iron than in others, depending largely on the heat treatment and composition. For example hard steel has a remanence about two times that of soft iron,[1] hence the use of hard steel for bar magnets, rather than iron which is annealed. It is believed by the writer that the magnetite that becomes strongly polar and forms lodestone, is chiefly ferromagnetic ferric oxide, or oxidized magnetite, which has a remanence about three times that of ordinary magnetite.[2]

The evidence which supports this hypothesis deals with the composition and occurrence of lodestone.

Composition of Natural Lodestone.—In a recent publication [3]

[1] Landoldt Bernstein, p. 1234.

[2] R. B. Sosman and E. Posnjak, "Ferromagnetic Ferric Oxide Artificial and Natural," *Jour. Washington Acad. Sci.*, 15, 1925, p. 337.

[3] W. H. Newhouse and W. H. Callahan, "Two Kinds of Magnetite?" ECONOMIC GEOLOGY, 22, 1927, pp. 629–632.

there were described a number of occurrences in which a brownish magnetite partly replaced earlier ordinary bluish magnetite.[4]

Further examination has shown that all the specimens from the several localities described, which show the brownish oxidized magnetite are lodestone, whereas those not showing brown oxidized magnetite or a mottling (presumably due to submicroscopic oxidation) are not polar. Furthermore, the strength of polarity as determined by the ability of a specimen to pick up iron filings, was found to be roughly proportional to the amount of oxidized magnetite present, and to be often markedly related to the areas of this mineral.

In the fifty-nine polished sections reëxamined[5] from the previous study, twenty-two were found to be polar and to contain brownish magnetite, while the remaining thirty-seven were non-polar and showed no brownish replacement magnetite.

The specimens just described were collected and polished without the knowledge that they were lodestone. After it became known that they were polar, a number of lodestone specimens were obtained from the Institute Mineral Collection and Ward's Natural Science Establishment. These were polished and examined for "oxidized magnetite." Most of them show it, whereas others show the mottled surface mentioned before, but a few show no variability that the writer can detect.

In hand specimens strong lodestone almost invariably shows signs of oxidation on the surface to limonitic substances. On polishing such specimens there is frequently found a close relationship between the largest areas and veinlets of brownish oxidized magnetic and the most highly corroded and limonitic part of the specimen. No specimens of lodestone which are strongly enough polar to be labelled such in a mineral collection, have been found which are entirely free from hematite veins.

The evidence for lodestone being related to oxidation in single specimens is supported by the field occurrences.

[4] An X-ray powder photograph of a mixture composed of about one half the ordinary bluish magnetite with the other half brownish replacement magnetite gave a pattern identical with that of ordinary magnetite.

[5] Economic Geology, 22, 1927, pp. 629–632.

Occurrence of Natural Lodestone.—Good data on the occurrence of lodestone are not abundant in the literature. The following descriptions, however, give some idea of pertinent geological relations. At the Windpass Mine, B. C., according to Uglow and Osborne,[6] "The variety of magnetite known as lodestone occurs abundantly near the surface, particularly near the eastern and western extremities of the ore shoot . . . the lodestone is black with a bluish tint, porous and rusty with iron hydrate, and possesses strong polarity and magnetic properties. . . . Under the microscope the lodestone shows a rough pitted surface without visible structure. Magnetite (dense, black crystalline variety, without polarity) is the earliest metallic mineral, and constitutes a large part of the mineralization, both within the shear zone and as impregnations within the wall rocks."

Detrital magnetite in the superficial beds and clays and in the rivers in Madagascar is frequently changed to martite, which is sometimes polar according to Lacroix.[7]

"La transformation plus ou moins complete en hematite (martite) est frequente. Cette magnetite est parfois magneti-polaire." . . . This same author describes elongated crystallites of magnetite from Puy de Dome which are oxidized to martite and show magnetic polarity.[8]

The occurrence at Magnet Cove, Arkansas, as described by Williams, suggests that oxidation may have taken place to some extent.[9]

> It is commonly believed in the Cove that this "magnet ore" as it is called, exists only on the surface and that as soon as one penetrates below the top of the ground the deposit ceases. This is in part true, for the "float ore" is the accumulation of centuries. It has been separated out from immense quantities of syenite, which has been little by little decayed and been washed away, leaving only the exceedingly heavy lodestone near the place where it was originally formed. . . . Much of the ore found is lodestone or natural magnet ore, while the rest of it is simply massive magnetite and is not polarized. By piling the latter into heaps with some of

[6] W. L. Uglow and F. F. Osborne, "A Gold-cobaltite-lodestone Deposit," Economic Geology, 21, 1926, p. 288.

[7] A. Lacroix, "Mineralogie de la France," 4, 1910, p. 336.

[8] *Op. cit.*, pp. 325–329.

[9] J. Francis Williams, Ann. Rept., Geol. Survey Arkansas, 2, 1890, pp. 180–181.

the polarized mineral it has been found that the non-magnetic pieces gradually become polarized and often become as strong magnets as some of the originally polarized pieces. The magnetic ore is usually found in smooth, round masses, entirely free from adhering pieces of other minerals, thus showing how complete the weathering has been.

This same feature of oxidation is further suggested by the experience of A. C. Lane, who states [10] that: "It is my impression that lodestone is very frequently related to fissures, joints, or shear zones in magnetite ore."

Lodestone from the Dover, New Jersey, magnetite ores, occurs in one specimen from the Richards mine. The specimen contains brownish magnetite developed along fractures in the normal magnetite. Some float ore from near Suckasunny also is lodestone and shows much alteration to limonite on the outside of the specimen. Polished sections show brownish oxidized magnetite most strongly developed in the normal magnetite near that part of the surface of the boulder which is most limonitic. In general lodestone is almost unknown in the mines of the area according to W. Spencer Hutchinson,[11] who has had a wide experience in this field.

The natural ferromagnetic ferric oxide which was analyzed and described by Sosman [12] was polarized. It came from a gossan deposit in the Shasta County Copper district, California.

Summary and Discussion.—Two features would seem to be necessary for the formation of lodestone. First a magnetite with high remanence (residual magnetization), and second a magnetic field to produce polarity in it.

Sosman [13] has shown that the remanence of natural ferromagnetic ferric oxide is about three times that of ordinary Mineville, N. Y., magnetite. The evidence points to such oxidized material as forming lodestone. To summarize: the field evidence points to oxidation as being one of the causal factors in the formation of lodestone, and the microscope in a large percentage of cases localizes this oxidation to the product "oxidized magnetite." In most

[10] Personal communication.

[11] W. Spencer Hutchinson, personal communication.

[12] *Op. cit.*, p. 332.

[13] *Op. cit.*, pp. 336–337.

of the cases where visible "oxidized magnetite" was not seen under the microscope a mottling was observed, which may be due to a submicroscopic intergrowth of magnetite with "oxidized magnetite." This argument has weight in view of the fact that visible areas of "oxidized magnetite" frequently blend gradually into magnetite with mottled areas in which individual particles can not be distinguished.

On the other hand a few lodestone specimens were found showing no "oxidized magnetite" and no visible mottling in polished surface. They do, however, contain later hematite veinlets and limonitic alteration on the surface of the specimens. Submicroscopic oxidation may be present.

With regard to the means of inducing polarity the evidence is not clear.

Lundberg [14] states that lodestone is commonly found in Sweden and Finland on the surface at the northern end of the orebodies. This suggests that the concentration of the earth's field by the orebody at this point is sufficient to induce polarity. Similar evidence that it occurs on the ends of ore shoots is afforded by Broderick's work [15] on magnetite ore in Minnesota. The occurrence on the ends of the ore shoot at the Windpass Mine, B. C., will be recalled.[16]

Since the magnetic field is usually strongest on the ends of the orebody, magnetostriction [17] may well cause some localization of "oxidized magnetite" there due to stresses set up along crystal boundaries. As is well known, stressed crystals are more easily attacked by solutions than others. There would then be a tendency for more rapid oxidation by solutions in the stressed crystals at the ends of the magnetite mass.

[14] Hans Lundberg, Swedish American Electrical Prospecting Company, personal communication.

[15] T. M. Broderick, "Magnetic Surveys of the Magnetite Deposits of the Duluth Gabbro, Eastern Minnesota," Economic Geology, 13, 1918, pp. 35–49.

[16] W. L. Uglow and F. F. Osborne, *op. cit.*

[17] *Physical Review*, 24, 1924, p. 60. Magnetostriction is the property which certain substances have of contracting or expanding when placed in a magnetic field. Magnetite contracts along directions parallel to the digonal and trigonal axes and expands along the tetragonal axis when placed in a transverse magnetic field. In a longitudinal magnetic field it expands parallel to the first two named axes and contracts in a direction parallel to the latter.

In brief the hypothesis is advanced that lodestone is generally formed from oxidized magnetite (ferromagnetic ferric oxide) which is known to possess a higher remanence than ordinary magnetite (ferro ferric oxide).

The polarity is probably largely induced by a concentration of the earth's magnetic field chiefly at the ends of an orebody but occasionally at points within the magnetite orebodies due to irregularities of mineralization or brought about by faulting.

Acknowledgment.—Thanks are due to Professor W. S. Franklin of the Physics Department, who very kindly reviewed part of the conclusions.

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A UNIQUE FELDSPAR DEPOSIT NEAR DEKALB JUNCTION, N. Y.

B. M. SHAUB.

FELDSPAR is as an important non-metallic mineral, because of its value in certain industries, such as the manufacture of pottery and abrasives. A number of deposits are being operated in the United States, the material in every case being obtained from pegmatites, most of which occur in schists or gneisses, but rarely in other types of metamorphic rock.

The deposit described in this paper is located in northern New York state, 3.9 miles southwest of DeKalb Junction, St. Lawrence County, and seems worthy of description because of its unique geological occurrence, and mineralogical associations.

It was discovered by J. H. McLear in 1907, and has been operated more or less continuously ever since, first as an open cut, and later by underground workings, the total production up to the present time having been over 120,000 tons. As a result of these operations, an opportunity has been afforded to gather information regarding the geology of the deposits, which have received only passing mention in the literature.

Previous Work.—D. H. Newland in 1916[1] made brief reference to the deposit, commenting on the fact that the feldspar showed no iron stain, and practically no iron bearing silicates, although there are occasional grains of pyrite in the quartz that occurred mainly as an intergrowth with the feldspar. The latter he classed as white perthitic microcline intergrown with albite. The crystals of feldspar were said to range from 6 inches to 3 feet in length.

A similar description of the deposit is given by Cushing and Newland[2] but they state in addition that the " porphyritic granite

[1] " Quarry Materials of New York," N. Y. State Mus. Bull. 181, p. 169, 1916.

[2] " Geology of the Gouverneur Quadrangle," N. Y. State Mus. Bull. 259, p. 116, 1925.

of this region shows a well marked tendency to develop pegmatitic phases, and its usual low iron content is favorable to the occurrence of feldspar with a minimum admixture of dark silicates that are the bane of most quarries."

GEOLOGIC FORMATIONS.

The rock types in the region surrounding the feldspar deposit have already been described by Cushing and Newland,[3] and include the following:

I. Grenville series consisting of (1) Mostly massive, pure crystalline limestones with occasional thin bands of schist or quartzite. (2) Rather impure siliceous limestone. (3) Various schists, usually mica or pyroxene rocks, often with tourmaline; thin bands of quartzite and limestone. (4) Rusty gneiss, usually quartzose and pyritic.

II. Igneous rocks, consisting of: (1) Porphyritic biotite granites, usually gneissoid and much involved with amphibolite. (2) Gneissoid granites believed to be much older than the other granite and of Laurentian age. (3) Amphibolites much cut and soaked by the porphyritic granites and probably of diverse age and origin.

III. Cambrian rocks, consisting of Potsdam sandstone, representing residuals of erosion.

All of these rock types are located within 1½ miles of the feldspar deposit, with the exception of the gneissoid granite which is found about 3 miles to the north.

The Grenville series, according to them, is strongly folded, has a general strike to the northeast, a prevailing dip to the northwest, and a plunge to the northeast of about 20–25 degrees.

The massive pure crystalline limestone is of a white color, and varies from fine to coarse texture. Phlogopite, graphite and small grains of pyrite are invariably present. Some dolomitic limestone occurs, but it is not abundant. In the limestone, tremolite is quite common in many localities, and light-colored pyroxene may also occur.

Cushing and Newland[4] divide the impure limestones of the

[3] *Idem*, pp. 18–50.

[4] *Idem*, pp. 20–22.

district into two types, namely: (1) Those which are metamorphosed impure limestones, and (2) those which owe their mineral impurities to contact metamorphism. Of these, the first is widespread in the Gouverneur quadrangle, and the second is of local occurrence and unimportant.

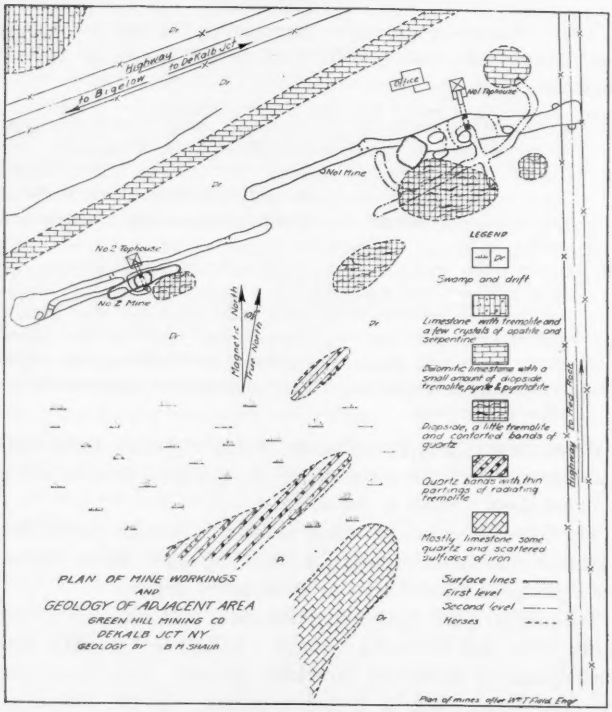

FIG. 1. Map of feldspar deposits.

One portion of the limestone seems to have been originally quite siliceous, and this has by metamorphism given rise to siliceous marble, or in extreme cases even quartzite. In some phases the quartz occurs as thin bands in the crystalline limestone.

The impure limestones formed by contact metamorphism, they state, may contain 50 per cent. or over of pyroxene and scapolite.

Rock Types Associated with the Feldspar Deposit.—In the immediate vicinity of the feldspar deposit, the rocks are practically all calcareous members of the Grenville series, but they contain a greater or less abundance of silicate minerals.

The several types that occur, so far as they could be determined from separated outcrops, are shown in Fig. 1, and include:

1. Limestone with tremolite and a few crystals of apatite and grains of serpentine.
2. Dolomitic limestone with small amounts of diopside, tremolite, pyrite and pyrrhotite.
3. Diopside rock containing a little tremolite, and contorted bands of quartz.
4. Quartzite with some limestone and diopside.
5. Banded quartzite with thin partings of radiating tremolite.
6. Limestone with some quartz and scattered sulphides of iron.

It will be seen from Fig. 1, that relatively pure limestone occurs in the northeastern and southern part of the area. The former is medium coarse and contains radiating, colorless crystals of tremolite, a small amount of apatite and a little disseminated pyrite as the chief accessory minerals. Although most of the tremolite is fresh and unweathered, it may locally show alteration to talc and serpentine. There is little or no quartz. The southern limestone is medium coarse, and commonly brownish red in color, due apparently to hematite of possibly high temperature origin. It occurs not only in the calcite, but also in quartz crystals lining cavities in the limestone. Microscopic crystals of feldspar, altered in part to later calcite, are present, as are specks of mica and pyrite. The absence of diopside or tremolite may be due to lack of magnesia in the limestone. The occurrence of the above minerals in the limestone is probably due to magmatic solutions that have permeated it.

The limestones to the south of the feldspar deposit seem to have been more impregnated by foreign minerals than those on the north, although the latter are closer to it. This may be due to

one of two reasons: (1) The magmatic solutions originated from some source directly below, or (2) the solutions moved more easily along the bedding planes of the limestone than across them, and as these beds dip to the northwest, it would tend to deflect the solutions towards the feldspar and to the south of it, rather than across the beds to the limestones on the north.

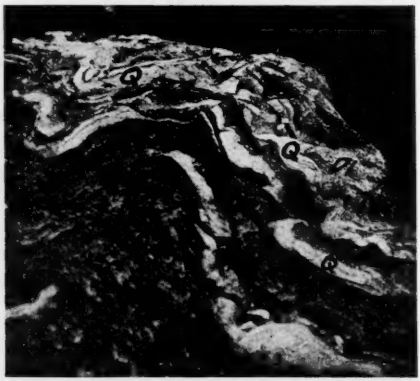

FIG. 2. Contorted bands of quartz (Q) and diopside (D), wall of feldspar deposit.

Referring to Fig. 1, it will be noticed that to the north of the southern limestone there are two ledges of quartz-tremolite rocks, which consist of bands of quartz up to a few inches thick separated by thin bands of colorless, radiating tremolite. Scattered grains of pyrite occur in the quartz-tremolite bands. The quartz grains are more or less interlocked and the bands of this mineral are folded without being fractured, as a result of deep-seated metamorphism.

Next on the north is a calcite-diopside-quartz rock of granular texture, the quartz occurring in bands, and the calcite containing diopside grains and small apatite crystals. The entire rock shows evidence of having been subjected to flowage, as the quartz bands are contorted, Fig. 2, and the apatite crystals are not only doubly

curved but show wavy extinction, Fig. 3. The diopside replaces the calcite. Cavities lined with quartz crystals are found in the rock, and on the crystals are bright red hematite scales and glistening crystals of magnetite, both evidently deposited from magmatic solutions.

Following the preceding to the northward, and representing perhaps another phase of it, is the diopside-quartz rock which forms the walls of the feldspar deposit. Here the quartz is in irregular bands which may show contortions.

On the north side of the feldspar deposit no such series is noted, but there is a low ridge of dolomitic limestone carrying pyrite, pyrrhotite, and a little tremolite with associated diopside. The latter weathers out to resistant knots of later calcite, serpentine and talc. It may be similar to the serpentine-talc knots in limestone, described by Cushing and Newland[5] as occurring in the limestone at Edwards, N. Y. This dolomitic limestone, however, as will be described later, grades into a zone of diopside-tremolite-quartz rock which forms the northwest wall of the feldspar deposits, but does not outcrop.

Dikes.—The only probable dike rock in the vicinity of the feldspar deposit occurs to the southwest of the No. 2 mine. The chief silicate in it is pyroxene, and the feldspar is mostly microline with some albite. There is little or no quartz, and a few grains of biotite. The very fine grain of the rock and associated minerals suggest the possibility of its being a dike.

THE FELDSPAR DEPOSIT.

The feldspar deposit forms roughly tabular masses in the Grenville series of limestones and quartzites; two of these bodies having been developed (Fig. 1).

The No. 1 deposit strikes approximately N. 65° E., and has a variable dip of from 45° to 90° to the south. It has known dimensions of 850 feet along the strike, and 115 feet on the dip, with an average width of 50 to 60 feet in the main part. The deposit is really separated into three more or less sheet-like masses

[5] *Idem*, p. 21.

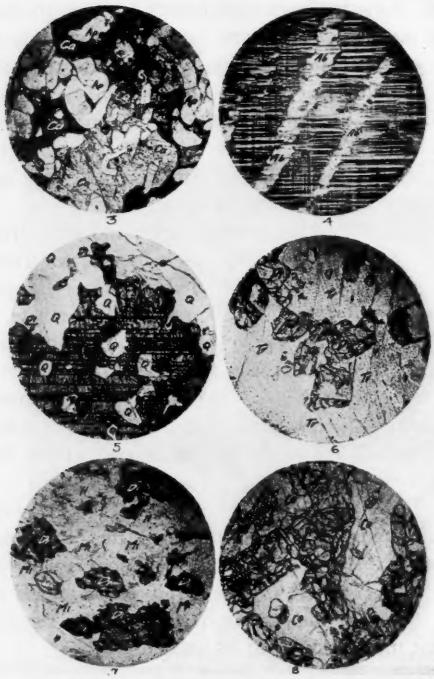

FIG. 3. Recrystallized Grenville limestone. Calcite (Ca), Apatite (Ap). ×9.

FIG. 4. Section showing ex solution stringers of albite (Ab) crystaltalized from solid solution in microcline. ×7.

FIG. 5. Large crystals of diopside (Di), partly replaced by quartz (Q).

FIG. 6. Residual grains of diopside (Di) a large tremolite crystal (Tr). ×9.

FIG. 7. Diopside (Di) replaced by microcline (Mi). Titanite (Ti). ×9.

FIG. 8. Rounded diopside grains (Di) with residual calcite (Ca). ×9.

of pure spar, which are separated by impure feldspar and rock impregnated with silicates.

The No. 2 feldspar body is more regular, consisting chiefly of a sheet-like mass, 480 feet long and striking approximately N. 65° E. but its line of strike, if extended, would pass slightly south of the outcrop of the No. 1 deposit. Its dip is about 90° throughout. The width varies from 7 to 15 feet, and it has a known depth of 40 to 70 feet. The southwestern end widens out into a bulb-like mass, and from it a branch returns parallel to the main body (Fig. 1), but ends by grading into the wall rock.

Texture and Mineralogy.—Although the feldspar deposit has a pegmatitic texture, no graphic intergrowths of feldspar and quartz were noticed. The chief mineral in the deposit is feldspar; next to it in order of abundance is quartz, and in subordinate amounts there occur tremolite, phlogopite, titanite, diopside, serpentine and talc. Other associated minerals occurring in very minor amounts are: calcite, pyrite, pyrrhotite, apatite, tourmaline, biotite, rutile, chlorite, molybdenite, allanite, actinolite, kaolinite, magnetite and hematite.

Feldspar.—The feldspars range from fine grains up to crystals approximately a meter long, with the average from 5 to 15 centimeters.

The feldspar in the larger crystals is a perthite, and the intergrowths of the two feldspars can be seen in the hand specimens due to the difference in the index of refraction. In these perthites, stringers of albite (Fig. 4) occur in microcline or less commonly stringers of microcline in albite.

This relation between the feldspars has been described by Alling as "ex solution."[6] It is supposed that the mineral in the stringers represents one crystallizing from solid solution in the enclosing mineral, from a saturated condition at a higher temperature, during the process of cooling.

The stringers of albite in microline are of two distinct kinds, viz. (1) wide bands plainly visible in the hand specimen, and (2) very narrow discontinuous lens-like stringers of microscopic pro-

[6] *Jour. Geol.*, vol. XXIX., p. 222, 1921.

portions, which are often roughly arranged en echelon. These two types may represent two distinct phases of cooling in the deposit. The first represents a long period of slowly declining temperature during crystallization, when the temperature of the deposit was decreasing very slowly due to the supply of heat by magmatic solutions and by the exothermal nature of the crystallizing minerals, the process of exsolution being slow enough to allow diffusion through the solid microcline of the albite to the wide bands, and the diffusion of the microcline from the region of the bands to that from which the albite diffused.

The microscopic bands represent that period when heat was no longer supplied by magmatic solutions or the heat of crystallization and the cooling became rapid in comparison. This rapid cooling did not permit the diffusion of the albite to the initial bands already developed, but required many new ones to be formed in a comparatively short time and close together, as the albite was forced from solution in the microcline, diffusion being too slow to permit its traveling any distance.

The en echelon arrangement of the lens-like stringers is to be expected, for this arrangement offsets the wide portion of the lenses, thus making a more uniform distribution of these centers to which the albite diffused.

The fine-grained portions of the feldspar show a more nearly equal distribution of the two types of feldspar, the albite being probably more abundant than the microcline. The average composition of a number of these fine-grained feldspar masses would probably closely approximate the eutectic composition of these two feldspars.

Quartz.—This mineral is universally present, usually as a clear or faintly smoky variety. When finely fractured it appears white or translucent and so nearly resembles the feldspar in appearance that one often has to look closely in order to distinguish it.

Tremolite.—This occurs sparingly in light greenish crystals throughout the feldspar body. The crystals are usually small but large ones usually occur in the impure portions of the feld-

spar, and along a part of the hanging-wall contact. Tremolite has been replaced by quartz, phlogopite, titanite and the feldspars.

Titanite.—Brownish wedge-shaped crystals of titanite are sparingly scattered through the feldspar deposit. In the impure portions, especially where greenish tremolite and residual calcite occur, titanite crystals 3–5 cm. across occur abundantly. Occasionally in the contacts a band of tremolite and titanite crystals occur. It was evidently a late mineral to form.

Phlogopite.—This mineral is not abundant and is usually associated with those portions of the deposit which are especially impure from the presence of silicates and again where residual calcite is present. Where evidence is obtainable from thin sections, the phlogopite appears to antedate the feldspar.

Diopside.—Well-developed crystals of diopside occur sparingly throughout the deposit associated principally with the other silicate impurities, but they are often isolated in very pure feldspar. They appear to be one of the early minerals to form and the enclosing ones are moulded about them. Later conditions partly altered these crystals to serpentine, talc and calcite.

Other Minerals.—Of these, serpentine and talc are the most abundant and occur disseminated through the feldspar in more or less segregated masses which vary from a light gray to black in color.

There is very little pyrite associated with the feldspar, although a few crystals of albite showed thin films of this mineral along the cleavage planes (Fig. 11).

Wall Rock.—The wall rock of the feldspar deposit wherever observable is found usually to be made up of a mass of translucent rounded grains or bladed crystals of diopside and tremolite with irregular bands of quartz, which are often discontinuous, as well as being sometimes folded. Well-developed crystals of diopside occur rarely along the contact portion of the walls. The bladed variety of this mineral appears to have been most susceptible to alteration, and has in a few instances completely changed to serpentine. Here and there one finds masses of residual calcite, which probably represent some of the original dolomitic limestone

from which the magnesia has been leached, but these are more abundant at the No. 2 than the No. 1 mine. On the one hand this mixture grades into the feldspar body, as will be described later, and on the other it passes into the dolomitic limestone, a transition that can be well seen in the walls of the shaft at No. 1 mine.

In places the calcite grains are disseminated through the diopside, and the two are difficult to distinguish with the eye because of their similarity of color. Large masses of coarse-grained calcite may occur, having not only associated grains of diopside and calcite, but quartz veins with diopside borders cutting into the same.

Light-greenish tremolite, titanite, phlogopite crystals are commonly associated with secondary silicate impurities near the contacts. Isolated crystals of feldspar up to 5 cm. across are of frequent occurrence in the diopside of the wall rock near the feldspar body, the feldspar having replaced the diopside.

Pyrite grains and crystals are sparingly distributed through the wall rock, and sometimes form irregular masses 5–7 cm. in diameter.

The structure of the wall rock is massive, except for the quartz bands, which in general dip to the northwest, although there are numerous local exceptions to this. In the east end of No. 1 mine the bands seem to form several compressed folds. Vugs are rare in the wall rock, but some lined with calcite and talc were noted.

Sections of the wall rock indicate quite clearly that the diopside is the oldest of the introduced minerals, and that it has been replaced by quartz, tremolite and the feldspars (Figs. 5–7). During the later processes, quartz also replaced tremolite, the feldspars, and mica, and in a few instances calcite was observed to have replaced the feldspars. Pyrite was among the latest minerals to crystallize.

The question may be raised whether the quartz bands were original in the dolomitic limestone, but this is negatived by the fact that the limestone outcropping just north of the wall rock is

non-siliceous, and by the clear evidence of the replacement of diopside by quartz (Fig. 5).

The bands might, it is true, reflect differences in structure in the dolomitic limestone, or they might have been caused by the solutions moving more readily along the bedding planes than across them; but even without this, irregular banding might develop, for it is known that this structure has been produced in gelatinous and porous materials by precipitation from solutions diffusing through them.[7] The porosity of the diopside rock may have been sufficiently great to act as a porous material.

Magnesia and lime seem to have been the critical mineral components which usually determined whether diopside or tremolite would crystallize. With a scarcity of magnesia and abundant lime and silica, the mineral to crystallize would be diopside. This was the condition which existed during the first stages of hydrothermal metasomatism of the dolomitic limestone, in which diopside replaced the limestone (Fig. 8).

During the later stages when diopside was metasomatically altered, the magnesia went chiefly to talc-serpentine impurities, and into the light-green tremolite crystals which are so conspicuous along some of the contacts, and associated with the silicate impurities in the feldspar body. It is understood of course that temperature conditions might be the deciding factor as to which of the above silicates should be formed.

The contacts between feldspar and wall rock, with one exception, are not sharp, there being a gradation from one to the other. This ranges from a few inches to several feet, and is accompanied by an increase of diopside, and decrease of feldspar. There are no concentrations of impurities along the walls except where locally they extend as segregations well into the adjacent parts of the feldspar body.

Pockets of impure feldspar in places extend into the wall rock and a few have been followed a short distance. One was traced into the wall a distance of 20 feet, an area of 5–10 square feet of impure spar being exposed in the face of a drift. In this case,

[7] H. B. Weiser, "The Hydrous Oxides," p. 167, 1926.

as in others, the feldspar grades into a diopside quartz wall along with tremolite, titanite, phlogopite, and other silicates. In one pocket some residual calcite from the dolomitic limestone is present.

The typical contact is represented by a gradation of feldspar with only a small amount of diopside into diopside wall rock with only a few crystals of feldspar. At only one place, in the open pit of No. 2 mine, was a sharp change noted, and here (Fig. 9) clear cut tongues of feldspar project into the wall rock. The gradation, however, is often hard to trace with the eye owing to

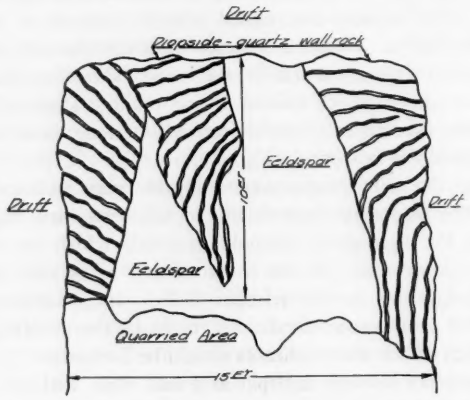

FIG. 9. Sketch showing massive, feldspar cutting into banded diopside-quartz wall rock.

the similarity in color between the feldspar and quartz-diopside rock.

The minerals in the transition zone are usually diopside and the feldspars. Tremolite, drab-colored diopside crystals, phlogopite and titanite are commonly more abundant in this zone than in the feldspar body in general, and large crystals of albite are apparently more abundant here than elsewhere in the deposit.

Especially interesting and well developed contacts occur in

the south walls of the open pits of No. 1 and No. 2 mines and also along the south wall, west end of No. 2 mine. In the latter, well developed bands of tremolite, titanite, and quartz, separate and penetrate the wall rock and the feldspar body (Fig. 10). The order of occurrence from the diopside wall rock is: (1) tremolite crystals which penetrate the diopside wall rock 5–7 cm.; (2)

FIG. 10. Banded contact between feldspar and diopside wall rock. Quartz (Q), Tremolite (Tr), Titanite (Ti), Diopside (Di), Bipyramidal quartz crystals (Qbp).

titanite in a band 1–2 cm. wide, which cuts across tremolite, quartz, feldspar and phlogopite crystals that may be in its way; (3) a band of quartz (containing bipyramidal quartz crystals) which grades into feldspar. The chief feldspar associated with these bands is albite.

In seeking to explain the development of this peculiar grouping of minerals along the south contact, it would seem as if temperature change and mixing of solutions might be more important factors than the character of the wall rock. Although temperature change might be of importance it should hardly limit condi-

tions to such a narrow zone, and it seems more probable that mixing of solutions was the dominant cause. It seems not unlikely that they were crystallized from solutions which in part rose along the south wall of the deposit, and in part emanated from the crystallizing mass of feldspar. It was these same solutions, probably, which deposited the small amounts of allanite and rutile found in this border zone.

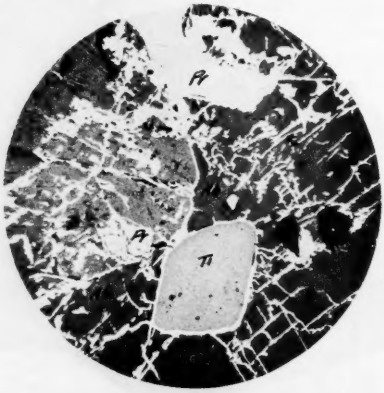

FIG. 11. Polished surface showing albite (Ab), titanite (Ti), and pyrite (Pr), the latter replacing albite along cleavage planes. × 50.

Segregations.—At several places in both the feldspar, and the diopside wall rock, there occur segregations of minerals which are in large part not found distributed through either the feldspar or the wall rock. One series of these has usually been found at intervals of about 250 feet horizontally along the north side of the feldspar deposit, and from top to bottom of the drifts. Megascopically these masses appear to consist of a mixture containing small crystals of black mica, pyrite, and a dark-green ground mass of albite, but in addition there are small amounts of pyrrhotite, tremolite and titanite.

Microscopic study indicates that deposition was initiated by a segregation of the mica, which has been in part replaced by later

albite. Titanite replaces both albite and biotite, whereas the pyrite and pyrrhotite came later since they fill cracks in the sphene and albite and replace the latter. (Fig. 11.) The age of the tremolite is not certain. Although these masses occur more or less in the feldspar, they probably antedate it, in part at least, as is shown by the relation of the albite and biotite.

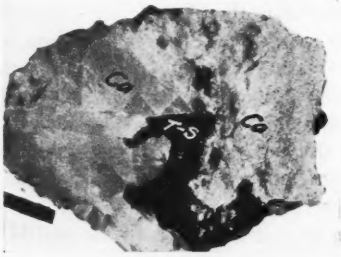

FIG. 12. Calcite (Ca) deposited from hot solutions, being replaced by impure talc and serpentine (T–S).

A second series of segregations is found chiefly within the feldspar body but they may extend in the diopside wall rock. These consist essentially of phlogopite, greenish crystals of tremolite, diopside and titanite, which are usually associated with residual fragments of calcite or diopside rock, a concentric arrangement of the minerals being more pronounced in those with the calcite core. In both cases hydrothermal alteration of the exterior has changed the diopside and perhaps tremolite to talc and serpentine.

A third type of segregation consists mainly of secondary silicates such as talc and serpentine. Although it seems certain that in some cases they have been formed in place by the complete alteration of the minerals of Type 2, still in other cases the talc and serpentine after their formation have been transported in solution and deposited by replacement in the feldspar, where they may form patches of some size, or have also replaced later vein calcite (Fig. 12). In some of these talc-serpentine masses there

were found druses lined with talc flakes and rhombohedra of calcite.

Horses of Residual Wall Rock.—At several places within the feldspar body residual masses or horses of wall rock occur. These according to Mr. McLear, who removed several of them, extend entirely across the feldspar bodies, and have straight nearly vertical walls with apparent sharp contact between the feldspar and the material in the horse.

Unfortunately most of these horses have been removed in mining, but a part of one which still remains shows that its assumed straightness is due to the fact that it is bounded by two parallel joints striking N. 80° W. across the feldspar body. It is furthermore found that there is a gradational contact consisting of tremolite diopside, a little phlogopite, and the feldspars.

So far as discernible, the constitution of the rock forming the horses is similar to that of the wall rock, and in all probability to that of the rock which occupied the space later filled by the feldspar body. The reason for their remaining is to be assigned to the supply of feldspar solution becoming exhausted.

Jointing and Faulting.—Irregular jointing is a conspicuous phenomenon throughout the mines, but two sets of persistent joints, crossing both wall rock and feldspar body, are distinguishable. These strike N. 65–80° W. and N. 45–60° E., dipping mostly very steeply to the south. Many of these joints show a small movement, probably confined to a slight rocking or reciprocating motion between the adjacent parts of the rock mass, but a number have developed into faults of varying magnitude.

The south or hanging walls in the central part and east end of No. 1 mine and west end of No. 2 mine consist of fault surfaces that dip steeply to the south, the one in No. 1 mine being a thrust fault.

The roof in the west end of No. 2 mine consists of a fault surface that dips 20° to the northwest. This fault cuts off the top of the feldspar body, and probably moved it to the southwest, where it is exposed in the No. 2 open cut, as this body of feldspar has a rock floor, in the east end, which dips to the west.

Paragenesis of Minerals.—Conditions of overlapping crystallization are evident between the segregations, feldspar body, contacts and the wall rock minerals; however, in these there are regular sequences of mineralization which differ slightly if any at the different places in the deposits. Beginning with the first minerals to replace the dolomitic limestone the paragenetic series is:

Diopside
Tremolite-actinolite
Tourmaline (?)
Bipyramidal Quartz
Biotite-phlogopite
Perthite-microcline-albite
Apatite (?)
Quartz (Major deposition in feldspar body)
Molybdenite (?)
Rutile-allanite
Titanite
Pyrrhotite-pyrite
Drusy Quartz
Hematite-magnetite
Talc-chlorite-serpentine-cryptocrystalline calcite
Flaky talc
Rhombohedral calcite (lining serpentine-talc cavities)
Vein calcite
Kaolinite-limonite

Although the quartz has crystallized over a wide range of conditions, most of it appeared after the feldspars. Where more than one mineral occurs in a line, it indicates their contemporaneous crystallization or probable occurrence in the order given. The minerals followed by a question mark are extremely rare in the deposit and consequently cannot be placed in the series with certainty.

ORIGIN OF THE FELDSPAR DEPOSIT.

Those who are familiar with the feldspar deposits of the United States, will recognize at once that the one here described is unique, although it is to be classed as a pegmatite. This class of deposit is usually divided into two types, acid and basic. However the deposit described above belongs to neither of these, for

it is characterized by having the principal constituents corresponding to those of the acid type, while the accessory constituents are of the basic type, in this case diopside, tremolite, phlogopite and titanite. Tourmaline and beryl or even garnet, so common in acid pegmatites, are rare or absent. The wall rock is limestone, in contrast to gneiss or schist of most other American localities that are worked for feldspar. In attempting to trace out the sequence of the events that took place there are certain major ones which seem fairly clear, but a few minor ones are obscure.

The general setting for the development of the feldspar bodies and their associated minerals is a series of Grenville limestones (in part at least dolomitic) and some quartzites which had undergone intense metamorphism as a result of which they were more or less strongly folded. These no doubt contained some silicates and even sulphides, such as we find scattered through the other crystalline limestones of this region, which in part might represent metamorphosed impurities, or in part have been deposited by magmatic solutions that permeated these rocks. This makes it a little difficult to tell whether all the minerals associated with the feldspar deposits are contemporaneous with them.

There were introduced into these rocks, along a line of fractures, magmatic solutions emanating presumably from the granite. These solutions attacked the dolomitic limestone, depositing in it successively by replacement, diopside, tremolite and quartz, giving rise to the curiously banded rock, now found, on either side of the feldspar body. In one place at least, where mining has exposed it, a gradational contact between the dolomite and silicate rock can be well observed. This pyroxenization of the dolomite was accompanied by a leaching of the magnesia in the original rock, leaving residual calcite, which is found in masses here and there in the wall rock and as residual crystals scattered generally throughout the wall rock, especially on the north side of the deposit.

Although it may be suggested that the bands of quartz represent original layers of this material in the dolomite, this seems doubtful for the reason that this rock on the north side of the

feldspar body is not siliceous. On the contrary, they are more probably the result of irregular rhythmic banding due to the coagulation of silicic acid gel which effected the silicification of the diopside and calcite.

The disposition of the bands would be roughly normal to the direction of motion of the solutions, which probably came from fractures dipping to the south. In this process, the solutions would not be expected to advance as a single wave, but instead they would deviate to follow the most permeable parts of the rock first and then advance from these new centers, and thus produce the irregular pattern of bands found in the wall rock.

Following the pyroxenization of the dolomitic limestone and the silification of the diopside, the solutions became feldspathic and replaced the quartz-diopside country rock, producing the feldspar body with a gradational contact between it and the wall rock. That this may be the correct explanation is also indicated by the fact that within the feldspar deposit are residual masses of rock which are similar mineralogically to the wall rock. The presence also of residual masses of limestone within the feldspar body leads to the belief that it may in part have replaced some of it as well. This would also result in the liberation of MgO and CaO, which combined with some of the constituents of the magmatic solutions to produce such silicates as phlogopite, tremolite diopside, and titanite, in the feldspar mass.

The quartz in the feldspar body is probably, to a large extent, a recrystallization of the quartz in the diopside-quartz rock, replaced by the feldspar. The evidence indicates that the quartz is in part contemporaneous and also later, continuing to crystallize after the feldspar and replacing it (Fig. 13).

Following this there was probably hydrothermal alteration of the silicates resulting in a very slight sericitization and carbonization of the feldspars, and the formation of talc and serpentine, chiefly from the diopside, and occasionally from the tremolite.

The occurrence of the feldspar body in the form of a roughly tabular mass might suggest that it represented an injection of rest magma at great depths, and while this may be true to a minor de-

gree, there are several facts which interfere seriously with a simple injection theory. They are: (1) Horses or residual masses of wall rock which at times completely cross the feldspar body; (2) a rock floor in places which consists chiefly of quartz and tremolite; (3) the distinct and widespread gradation from the feldspar body, thorough the quartz-diopside border zone, into the country rock.

This almost universal gradation of the feldspars and associated minerals into the diopside-quartz rock, supported by abundant

FIG. 13. Quartz (Q) in part replacing albite (Ab).

evidence of replacement of one by the other, and accompanied by the presence of high temperature minerals, seems to suggest very clearly a high-temperature deposit.

The roughly tabular outline is probably due to the similar orientation of the feeding channels or local short fractures in the country rock, or to a zone in which the minerals of the country rock were in an excessively strained condition, which made them more susceptible to replacement.

The horses remaining are due to the cessation of magmatic solutions before complete replacement.

The magmatic solutions probably came from the porphyritic

granite, and on leaving their source contained mineral components to develop acid pegmatites if injected into rocks other than dolomitic limestones.

COMMERCIAL PRODUCTS.

The chief use of the feldspar mined near DeKalb Junction is in the manufacture of pottery, most of it being shipped to Rochester, N. Y., or Trenton, N. J., where it is ground. A mill is now in the process of erection at the mines, and the grinding will be done there in the near future.

Prior to shipment the material is sorted into first and second grades. The lumps of the latter are then broken up by sledges to save the better portions of it.

The absence of iron-bearing minerals, and the low fusing point (said to be cone 7 or 1210° C.) make the product a desirable one.

ACKNOWLEDGMENTS.

The writer wishes to express his sincere thanks to Professor H. Ries for assistance during the investigation and for his suggestions in the preparation of the manuscript; also to Mr. J. H. McLear, discoverer of the feldspar deposit, for putting at the writer's disposal his time and assistance in examining the mines.

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ITHACA, N. Y.

EDITORIAL

THE ORIGIN OF THE MANCHURIAN MAGNESITE DEPOSITS.

THE magnesite deposits extensively scattered over a vast area of the pre-Cambrian magnesium limestone formation in the district of Ta-shih-chao, South Manchuria, have been fully treated by K. Niinomy.[1] As to the origin of these deposits, which has long been a topic of controversy among Japanese geologists, he has concluded that the deposits were formed by replacement of dolomite along bedding planes and fractured zones through the action of solutions containing much magnesia, and originated in a mass of granite deeply concealed beneath the surface. Criticizing Dr. Niinomy's paper, H. Nishihara has discussed the origin of these deposits,[2] concluding that they are of primary sedimentary origin.

I had an opportunity of visiting the magnesite district in 1922, when Dr. Niinomy was still studying at Cornell University, and arrived at an opinion the same as his. There remains very little to be added to his description as to the mode of occurrence and character of the ore and the country rock, but I would like to insert here a few important data from my old notebook in order to support his conclusion.

1. At Pai-hu-shan I found two dikes of a lamprophyre, one on the southern slope and the other on the northern, both cutting the magnesian limestone formation including dolomite and magnesite deposits. At Niu-hsin-shan I discovered a similar lamprophyre characterized by large hexagonal flakes of biotite, also cutting dolomite and magnesite deposits in the form of a large dike. The basic rock from Niu-hsin-shan is usually so highly decomposed that the original texture is scarcely revealed under the microscope

[1] ECON. GEOL., vol. XX., No. 1, 1925.
[2] ECON. GEOL., vol. XXI., No. 2, 1926.

except for the abundant porphyritic crystals of partially decomposed biotite. But that from Pai-hu-shan is comparatively fresh, and reveals the original character fairly well. It shows a panidiomorphic porphyritic texture with abundant megascopic phenocrysts of biotite and feldspars—mostly orthoclase now highly altered. This rock is a typical minette, a common basic differentiate from the granitic magma.

2. As Niinomy pointed out, a light-grayish schistose rock with silky luster containing abundant dark-colored mica flakes is frequently associated with the magnesite deposits and dolomite beds in Kuan-ma-shan and many other places. It occurs either interbedded between beds of magnesite or as walls of magnesite. It is tourmaline mica schist. Under the microscope it is seen to consist of blastoclastic grains of quartz, intermingled with abundant minute scales of sericite and fine needles of tourmaline. The sericite and tourmaline are arranged mostly along the schistosity, but sometimes across it. The blastoporphyritic mica, with a brownish or greenish color in thin section, 1–3 mm. in length, is commonly developed along the schistosity, but occasionally obliquely across it. It often shows a finger-like outline and is mottled or poikilitic in structure, with rounded grains of quartz. It is characterized by distinct pleochroism, very small optical angle and rather high indices of refraction ($\gamma = 1.593$). It is phlogopite. Inclosures of sagenitic rutile in characteristic arrangement of needles are very common.

The rock is evidently a contact-metamorphosed shale interbedded in the magnesian limestone series, the addition of boron by the mineralizers at the time of recrystallization being undebatable. On decomposition by percolating meteoric waters this rock is altered to a grayish-green massive rock, serpentinous in appearance.

3. Gneissic granite is widely exposed near the magnesite district at Ta-ling about 5 km. N.E. of the Kuan-ma-shan magnesite district. The rock is evidently intrusive in the pre-Cambrian magnesian limestone formation in question. The occurrence of abundant prismatic crystals of scapolite in the

coarse-grained magnesite and in the gray dolomite at Ta-ling and other places indicates a contact-effect by the granite. It should be borne in mind that the gray dolomite associated with the magnesite deposits and the magnesian limestone preponderant in this formation are compact in texture and show very little sign of schistose structure, and that those compact carbonate rocks consist of minute interlocking grains as revealed under the microscope, showing evident recrystallization. It is thus suggested that the contact-metamorphism was not effected very strongly in the places more or less distant from immediate contact with the batholitic mass, but the emanation of chlorine-bearing mineralizers caused the formation of scapolite. The permeation of Mg-bearing solutions to which was due the formation of magnesite was, of course, of a much later stage of magmatic solidification.

4. In the gray-colored compact carbonate rock forming the walls of the magnesite deposits at Niu-hsin-shan I found, here and there, networks of veinlets of a white to rose-colored coarse-grained carbonate. I thought at first, that the coarse-granular mineral was magnesite and the country rock dolomite. It was, however, found by analyses that both were dolomite with a nearly equal composition, as the following table shows:

Analyst, E. Minami.	Coarse-grained Dolomite in veinlets from Niu-hsin-shan.	Gray Compact Dolomite Forming Walls.
MgO	21.56%	21.20%
CaO	31.11	30.43
MnO	tr.	0.08
FeO	0.81	0.80
CO_2	47.02	46.34
Insol.	0.12	1.20
Total	100.62	100.05

It is highly probable that the coarse-granular dolomite forming veinlets was deposited from hydrothermal solutions that contained much magnesia, circulating through fissured zones, and the country rock, originally magnesian limestone, was permeated by the same solutions and changed to dolomite by replacement.

Thus I believe that future investigations will prove that the compact pure dolomite in thick beds so extensively developed in

this district in close association with the magnesite deposits were also formed by replacement of the magnesian limestone which had been the predominating member of the pre-Cambrian formation.

In conclusion, I am of the opinion that the beds and lenses of dolomite and magnesite in the pre-Cambrian terrane of the Ta-shih-chao district in South Manchuria were formed by replacement of magnesian limestone through the action of hydrothermal solutions containing much magnesia, and that the solutions were the residual liquids representing the final stage of the magmatic solidification; the granite mass exposed to the north of Ta-ling being a part of the solidified magma and the minette dikes exposed here and there in the magnesite district being a basic differentiate from the same magma.

TAKEO KATO.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE ORIGIN OF ARTESIAN PRESSURE.

Sir: Under the heading "The Origin of Artesian Pressure" Mr. W. L. Russell presents in this journal [1] a series of very striking arguments against the conception that the Dakota sandstone could be considered a continuous system of highly permeable strata extending without break from the Black Hills to the Missouri River. Among these arguments, the following ones should be pointed out as deserving particular attention:

Difference in geological age of the so-called Dakota formation of the Black Hills and the Dakota of the type locality.

Considerable local variations in thickness and frequent presence within the sandstone of intermediate layers of shale.

The lines of equal head to be practically independent of the boundaries of the outcrops.

Difference in head of the artesian water contained in upper and lower sandstone horizons of the same locality.

Conspicuous variations in the chemical composition of the artesian waters both in the horizontal and the vertical sense within the artesian region.

Occurrence of chemical admixtures to the water over very restricted areas.

Considering these arguments, there is little doubt that Mr. Russell's conception concerning the utter lack of uniformity and continuity within the sandstone deposits is correct. On the other hand, it is difficult to accept the theory that the sandstone deposits consist of a series of sandstone lenses which are completely separated from each other by practically impermeable strata. The character of the deposits (coastal plain deposits)

[1] ECON. GEOL., vol. 23, pp. 132–157, 1928.

rather suggests the presence in the ground of permeable lenses and pockets, interconnected with each other by veins and strips of material of a similar character, resembling in plan chains of permeable deposits imbedded in and interwoven with a very much less permeable matrix. Strictly lenticular deposits, hermetically sealed all around by almost impermeable shales, undoubtedly represent exceptions, although it is conceivable that they may be formed under unusually favorable circumstances.

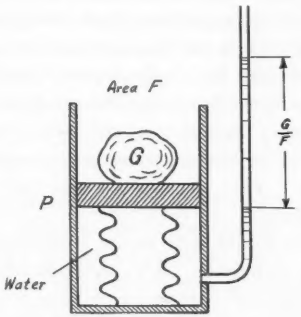

FIG. 1.

Yet, for the sake of getting at the fundamentals of Mr. Russell's theory, let us assume that Mr. Russell's conception concerning the lenticular character of the deposits be strictly correct. Granting this assumption, we will investigate whether or not artesian conditions could exist of the type Mr. Russell expects. The geological origin of the lenticular deposits would be approximately as follows: After the sand was deposited over a limited area with a closed boundary, it was completely covered with feebly permeable deposits. Immediately before this second process started, the sand occupied a certain amount of space equal to the volume of sand plus the volume of water. It is correct to assume with Mr. Russell that both the water and the individual sand grains are practically incompressible if compared with the sand, representing a disperse system. Therefore, if the thick-

ness and the weight of the feebly permeable overburden increases, the water contained in the voids of the sand inevitably comes under pressure. If the overburden was perfectly impermeable, this pressure would be almost exactly equal to the weight of the overburden. The working of the system (sand plus overburden) could be compared with the working of the test arrangement shown in Fig. 1. The space under a tightly fitting, frictionless piston P covering an area F is supposed to be completely filled with water, and the compressible sand is represented by the springs S. If loading the piston with the weight G, the compression of the springs would not change at all because they are very much more compressible than is the water. Furthermore, if connecting the reservoir with a very thin standpipe, whose volume content is very small, the water would rise in the pipe to an elevation G/F, indicating the existence in the water of a pressure of equal intensity. This phenomenon represents the nucleus of Mr. Russell's theory.

However, in the initial state of its formation, every clay deposit is relatively permeable. We could reproduce the condition which exists in this initial state by drilling a small hole in the piston of our apparatus, Fig. 1. Due to the presence of this hole, the springs would gradually come under pressure, causing the pressure within the reservoir to diminish. According to Mr. Russell, the leak through the roof of the sandstone lenses was so small that the water in the sandstone is still under a pressure equal to a very appreciable fraction of G/F (weight of the overburden per unit of area). In practice, the situation is still further obscured by the fact that the reservoir (the water-filled voids of the Dakota sandstone) was not covered with a rigid slab but by a clay deposit in a state of progressive consolidation, representing in itself a source of water. While consolidation goes on, water escapes towards the free land surface both from the sand and from the clay. If we would drill a hole in the sand layer while the consolidation of the clay still proceeds, we would obtain exactly the artesian phenomena Mr. Russell asks for. As a matter of fact, we repeatedly encountered such artesian conditions in

connection with test borings when tapping sand pockets located beneath very young, unconsolidated clay deposits in the vicinity of Constantinople. Hence, the problem of deciding for or against Mr. Russell's theory is reduced to answering a single question: Is it possible that the Graneros shales located above the assumed lenses of Dakota sandstone are still in a state of progressive consolidation? If not, there is no physical reason why the water content of the lenses should still be under pressure.

Fortunately, the combination of geological circumstances, subject to our inquiry, was found to be simple enough to be expressed by a differential equation. This equation and one of the solutions was published by the writer a few years ago.[1] The order of magnitude of the physical constants of the materials located in the Dakota region is also known. Hence, there is no obstacle against approaching the problem analytically.

Let h be the reduced thickness of the clay deposit in cms., that means the thickness the deposit would have if it should be compacted to a zero volume of voids.

t the number of years which have passed since the last increment of the clay deposit was laid down.

n_1 the degree of consolidation on the day when the last increment of the clay deposit was laid down, that means, the percentage of the weight of the clay deposit which no more produces a hydrostatic excess pressure in the water contained in the voids of the sandstone.

n the degree of consolidation of the clay deposit t years after the deposit was completed.

c the coefficient of consolidation of the clay in the cm. gram year system, expressing the relative speed with which the material consolidates under its own weight.

According to the writer, these quanties are connected with each other by the relation

$$1 - n = (1 - n_1)e^{-2c(t/h^2)},$$

[1] Terzaghi, Erdbaumechanik. Vienna, 1925.

whence we obtain

$$t = -\frac{h^2}{2c} \log_{nat} \frac{1 - n}{1 - n_1}.$$

In order to exclude any error tending to furnish for t a value which would be too small, we make the following unfavorable assumptions:

$n_1 = 0$, that means, not a drop of water has percolated out of the deposit while it was formed. Consolidation started after sedimentation was finished.

For n we assume a value of 0.99, considering the deposit as completely consolidated only when the hydrostatic pressure has dropped to 1 per cent. of the weight of the overburden.

$h = 400$ meters, that means, a value very much greater than the present real thickness of the strata located above the sandstone, the real thickness of the strata located above the sandstone, the real thickness ranging between 100 and somewhat more than 300 meters. By this assumption, we take into account the fact that part of the original clay deposit was removed by erosion. Finally, we assume that c has a value of 600 (cm. gram year system) which is less than ¼ of the consolidation index rate for fat blue Mississippi gumbo.

With these figures, we arrive at

$$t = -\frac{40000^2}{2.600} \log 0.01 = 6{,}200{,}000 \text{ years.}$$

Since the roof of the Dakota sandstone is of lower Cretaceous age, there seems to be no possibility that the water content of the voids of the sand will still be under an appreciable pressure derived from the weight of the overburden. Furthermore, if part of the overburden was removed by erosion after the consolidation of the clay deposits was practically complete, the subsequent expansion of both the sand and the clay should have caused any remnant pressure which still existed in the water to disappear completely.

There is another fact which is brought out by theory in a conclusive manner. If a system consisting of layers of sand and

of clay consolidates, the water flows everywhere in an upward direction, irrespective of stratification, provided the sand beds have no lateral outlet. Therefore, it is difficult to accept Mr. Russell's suggestion (page 153) that the water may be forced from a clay which is above into a sand which is below, thus producing an increasing pressure. The vast difference between the compressibility of the sand and clay does not alter this fact, because theory takes this difference fully into account.

Considering the elastic properties of a sand-clay system, it is also difficult to believe that salt and gas water was forced to an appreciable extent out of the Graneros shales into the Dakota sandstones by a horizontal pressure. It seems much more probable that the faulting tended to cut off communications within the system of strata, which in turn prevented the salt from being washed out as rapidly from the faulted section as it was removed from the undisturbed ones.

Concluding, the writer wishes to state that it seems to him still difficult to explain the existence of artesian pressure within the Dakota sandstone except by the traditional theory of artesian flow, supplemented by the theory of elastic behavior presented by Mr. Meinzer in the May issue of this same journal. The various arguments brought forth by Mr. Russell against the assumption of the existence of a continuous bed of fairly uniform permeable strata of sandstone by no means interfere with this conclusion because there is a wide margin between a free and a restricted communication between the individual aquifers. The limited spot-shaped areas furnishing salty water can very well be considered as lenses which communicate with the outcrop through a permeable vein without having an outlet with a permeability sufficient to induce an appreciable flow towards other permeable pockets located farther west. The same considerations apply to the difference in head between the water content in upper and lower horizons of the sandstone at the same locality. The lack of relation between the boundary of the outcrops in the Black Hills and the line of equal head merely proves that the effect on the head of variations in permeability is liable to be much more important than is the effect of the structural factors.

Mr. Russell has rendered to the profession a valuable service by clearly demonstrating that the hydraulic conditions within an apparently simple artesian aquifer are apt to be much more intricate than one is inclined to assume.

CH. TERZAGHI.

MASS. INST. OF TECHNOLOGY,
CAMBRIDGE, MASS.

ON THE USE OF THE TERM DEUTERIC.

Sir: In your November, 1928, number Mr. F. F. Osborne, in a paper describing the magmatic titaniferous iron ores, criticized the use of the term deuteric as used in a paper [1] written jointly by me and two of my former students, stating that it was a misuse of the term as originated and defined by Sederholm.

In defense of our use of the term, I will take the liberty, as senior author, of speaking for the three of us, as the two junior authors are widely scattered.

Sederholm [2] defined the term deuteric as follows: After a long discussion and description of late primary albitization and myrmekitization because of solutions, gases and liquids, which "belonged to the magma itself" and percolated through the rock, he says (page 141–142):

> I think that it would be advisable to discriminate between such metasomatic changes which belong to a *later* [3] period of metamorphism, *i.e.*, are secondary in the strictest sense of the word, and those that have taken place in direct continuation of the consolidation of the magma of the rock itself. I propose to call the latter deuteric, as distinct from secondary changes.

This definition seems to permit of only one interpretation; that albitization and other metasomatic changes caused by solutions

[1] Gillson, J. L., Callahan, W. H., and Millar, W. B., "Adirondack Studies, the Age of Certain of the Adirondack Gabbros and the Origin of the Reaction Rims and Peculiar Border Phases Found in Them," *Jour. Geol.*, vol. 36, pp. 149–163, 1928.

[2] Sederholm, J. J., "On Synantetic Minerals and Related Phenomena," Bull. de la Comm. Geol. de Finlande, No. 48, 1916, pp. 148.

[3] The italics are mine.

given off from the same magma from which the rock itself crystallized, which percolated through the already solid (or almost solid) but still hot rock, should be called deuteric. This was exactly the sense in which the term was used by us in the paper criticized by Mr. Osborne.

Mr. Osborne suggests that the terms pneumatolytic or hydrothermal would have expressed our idea more correctly. We studiously avoided the use of such general terms, since no one can know whether the solutions were pneumatolytic or hydrothermal. A general term was necessary, and that had already been supplied by Sederholm, "deuteric."

In a paper written in 1923 Colony[4] discussed this problem, stating:

> Sederholm describes as 'deuteric effects' certain products occurring as an intergrowth of two minerals at their contacts by reason of the action of magmatic end-stage emanations; but the structures thus described are very minute. The writer has extended the term to cover all magmatic end-stage emanation phenomena.

Following Colony, I described as deuteric effects the formation of titanite, allanite, and epidote, and the replacement of quartz and plagioclase by microcline and the chloritization of the biotite in the granodiorites of the Pend Oreille district in Idaho,[5] and published sketches showing deuteric magnetite, titanite and allanite from a number of rocks.

In a later paper[6] I described albitization and other effects in the granite of Conway, N. H., as deuteric.

Since the publication of these papers in January and August, 1927, I have seen no criticism, by letter or in print, from either Drs. Sederholm or Colony, or from any one else, of my use of the term deuteric.

I thus conclude that the term deuteric is established as covering

[4] Colony, R. J., "The Final Consolidation Phenomena in the Crystallization of Igneous Rocks," *Jour. Geol.*, vol. 31, pp. 169–178, 1923.

[5] Gillson, J. L., "Granodiorites in the Pend Oreille District of Northern Idaho," *Jour. Geol.*, vol. 35, pp. 1–33, 1927.

[6] Gillson, J. L., "The Granite of Conway, N. H., and its Druse Minerals," *Amer. Min.*, vol. 12, pp. 307–319, 1927.

those metasomatic changes in igneous rocks caused by the reaction between the minerals already formed and the emanations, gaseous or liquid, percolating through the solid, or almost solid rock, and which have been given off from the same magma from which the rock itself crystallized.

If the mineral changes were caused by solutions from a later period of metamorphism, or the intrusion of another magma, or from circulating groundwater, or by weathering; then the term deuteric should not be applied to them.

JOSEPH L. GILLSON.

MASS. INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

REVIEWS

Elements of Geophysics, as applied to explorations for Minerals, Oil and Gas. By RICHARD AMBRONN. M. C. COBB, translator. 372 pp., 84 illus., 1672 references. Translated from "Methoden der Angewandten Geophysik," Liesegangs Wissenschaftliche Forschungsberichte, Naturwissenschaftliche Reiche, Band XV., Theodor Steinkopf, Dresden and Leipzig, 1926. McGraw Hill Book Co., New York, 1928.

The purpose of the book is not to serve as a textbook for the execution of geophysical surveys, but, first, to provide a complete and well-balanced review of all the geophysical methods that may be used in economic geology, so that the geologist, mining engineer, layman or executive, who has to do with them or is considering the use of them, may come as completely as possible to understand their possibilities and applicabilities and, second, to provide for the practical geophysicist and others interested in applied geophysics, reference to the thought and literature on the subject.

The book comprises an introductory chapter on the development and present position of geophysical methods in prospecting; influence of the subsurface formations on the character of the gravitational field at the surface of the earth, including pendulum and torsion balance surveys; magnetic methods of investigations; the use of radio-active and atmospheric-electric measurements for geophysical prospecting; electrical methods of prospecting, the seismic method of prospecting, the distribution of temperature in the earth's interior and the use of temperature methods in applied geophysics.

In each subject, the elements of the pure as well as the applied theory are given, the geophysical instruments and their method of use are described, and the results of many applied geophysical surveys are shown and practically all published descriptions of geophysical surveys are mentioned. The literature on geophysics has apparently been thoroughly searched and a detailed review is given of the pertinent thoughts, theories, suggestions, observations, and data, and at the point of mention, direct references are made to the literature. There are 84 diagrams, sections, maps, and a bibliography of 1672 titles, and of 277 serials in which geophysical papers have been published.

The portions of the manuscript checked against the original by the reviewer were found faithfully to follow the German text. Minor revision and small additions of new material were made in a few places in

the book by Ambronn during the translation, but in general the book is of the date of the original, March, 1926, and the extensive literature of 1926, 1927 and first half of 1928 is not mentioned or listed. The typography is good and the illustrations clear.

The only adverse criticism which the reviewer has to offer is that in places not sufficient distinction is made between practically untried methods which theoretically should work and methods which have actually been proved successful. The general impression which the book gives in regard to the successful applicability of the methods in economic geology is slightly too optimistic. The book also would have been more convenient in many ways if it had been pocket-sized like the German original.

If the reviewer were allowed only one book on geophysics he would have to choose this. It will be the indispensable reference book of the professional geophysicist and the textbook of the elementary and advanced students of geophysics and of geologists, executives, and others interested in applied geophysics.

DONALD C. BARTON.

This Puzzling Planet. By EDWIN TENNEY BREWSTER. Pp. 328, illustrated. Bobbs-Merrill Co., Indianapolis. Price $4.00.

Carefully selected and attractively interwoven, the facts of biography and geology constitute the warp and woof of this new book by Mr. Brewster. The book is intended for amateurs and as such, the beginner will find in the volume an excellent orientation, while the expert will find a refreshing treatment of familiar topics. Chapter five, for example, on the rise and fall of the Wernerian "onion-coat" earth theory, is typically noteworthy as a demonstration of the author's skill in presenting his subject-matter and in generating a deep respect for the dramatic as well as the instructive qualities of the geologic story. The student, using a more formal text, will find this book a stimulating supplementary reader.

ROLAND W. BROWN.

Bulletin of the Institute of Practical Geophysics, Supreme Council of Public Economy, U. S. S. R. Vol. 2, 1926. Pp. 270. Leningrad, Russia.

I. Bahurin, The magnetic field of bodies of regular shape from the point of view of magnetometric studies (English abstract) 3–64

The paper gives the results of a mathematical study of the magnetic field of an oblate ellipsoid of revolution magnetized in the direction of its axis of revolution.

I. Bahurin, The work of the I. P. G. on the brown iron ore deposits (of the Tulo and Lipetzk districts) (English abstract) 65–82

The paper gives the results of magnetic surveys of iron ore deposits in the Tula and Lipetzk districts, with three maps. Although most of the anomalous vectors only slightly exceed the probable error of observation, a few are considerably larger and seem to correlate with the ore deposits. In one area of the Lipetzk district, the anomaly in the inclination amounted to 20′ and the anomaly of horizontal intensity amounted to 250 gamma. In the Tula district, the anomaly in the inclination was 34′, in the horizontal intensity 180 gamma, and in the vertical intensity 500 gamma.

E. Krakau, N. Malinine and M. Penkeviez, Magnetic Microlevelling carried out in the iron ore district of Lipetzk in 1925 (English abstract) 83–95

The authors occupied 237 stations with Brunner-Chasselon magnetic theodolites and Dover dipcircles.

I. Bahurin, The magnetic observatory in the coal basin of the Don and the magnetic survey near Makeyevka (English abstract) 96–106

The I. P. G. suggests the importance of a magnetic observatory in the Don coal basin for the registration of the variation of magnetic declination in connection with mine surveying and for geophysical prospecting in the southern part of the U. S. S. R.

N. Rose, Magnetic observations in the region of the coal fields of the basin of the Don (district of the village of Makeyevka) (English abstract) 107–123

The observations were made for the purpose of selecting a suitable site for the magnetic observatory.

A. Petrowsky, Basis for calculating the observations of earth currents (English abstract) 124–142

This paper is the continuation of a previous paper in which the mathematical expression was deduced for the potential in the zone surrounding a spherical electrode half sunk in the ground, and gives an analysis of that formula and a method for its application to the distribution of the field within the medium according to the deviation of a galvanometer included in the circuit between a pair of such electrodes. The observations in the field at Ridders Mine confirmed the theoretical deductions.

A. Petrowsky, Theory of the return Method (of radio prospecting) (English abstract) 143–176

The paper gives the result of a theoretical study of the quarter wave length method of radio prospecting, with deductions of practical interest for the use of the method.

W. Pavlinoff, An apparatus for the clibration of magnetometers (English abstract) 177–183

The apparatus consists of a system of two magnetic shells of large dimensions in a so-called Hemholz arrangement.

L. Bogojavlensky, On highly penetrating earth rays (English abstract) 184–195

Ninety stations were occupied over an area of 10,500 square meters of radium deposits in fissures in travertine in the Caucasus. The curves of equal intensity were elongated in the same direction as the fissures. The intensity measured seemed to be constant within three per cent, no matter whether the observations were taken a year apart or under different meteorological conditions. At 22 of the stations the radiations were absorbed by lead screens 1 cm. thick. The presence of radiation of greater penetrating power than the gamma rays of radium C were indicated. The effect of the radioactivity of the air was nil and of the upper soil negligible.

S. Girin, The advantages of continuous recording of the oscillation of the beam of a gravitational variometer (Russian only 196–200

P. Nikiforov, A preliminary report on the gravitational survey of the Eelitsky salt spring, summary for 1925 (Russian only) 201–202

P. Nikiforov, A simplified method of the calculation of the zero point of a torsion balance (Russian only) 203–231

P. Nikiforov, The Physical Principles of the gravitational method of prospecting (Russian only) 232–264

This paper is apparently a continuation of a paper of the same title in Vol. 1. Sect. 4 apparently gives a discussion of the interpretation of observed results on the basis of the curvature vectors, and Sect. 5 apparently is a discussion of the determination of local gradient and curvature effects and anomalies by some partly graphical method.

K. A. Kirillov, A Method of rapid calculation of the vectors of the Eotvos Differential Curvature in the case of a sloping stratum.

This volume, like its predecessor, is a notable contribution to the literature of applied geophysics. It amounts to several times as much as the total contribution of the English-speaking world during the same year. Much data of great interest are apparently buried from most of the world in the Russian of the text, and are only tantalizingly indicated by

the brief abstracts in English of some of the papers and by the diagrams and formulae of other of the papers. DONALD C. BARTON.

HOUSTON, TEXAS.

Underground Practice in Mining. By BERNARD BERINGER. Pp. ix + 255, Figs. 188, tables 13. Mining Publications, Ltd., London, 1928. Price, 20 s.

This profusely illustrated book deals with the different phases of underground work in a metal mine from the point of view of efficiency. It is intended to serve "as an up-to-date guide to mining method and practice for general managers and officials, and for the mining students." It discusses the principles underlying the proper support of workings, the construction of shafts, stoping, the application of explosives, compressed air practice in mining, ventilation, sampling, and mine organization. The treatment of all these subjects is clear and simple, and all explanations are elucidated by the use of numerous figures. Perhaps some of the methods suggested by the author for the construction of shafts, shaft stations, raises, winzes, etc., may not be in accord with American practice, but they all embody principles that may be applicable in a modified form anywhere.

Nearly all the machines commonly employed underground are described in detail, and examples are used to illustrate the way in which the data obtained by reading various instruments are applied in formulas, developed for the purpose of determining the conditions necessary to the proper ventilation of mine workings.

The book should be useful to any one interested in the proper management of the underground working of metal mines. It is well printed and sufficiently illustrated to serve as a convenient textbook. Its price, however, seems to be rather high for its size. W. S. BAYLEY.

Color Chart, National Research Council, Division of Geology and Geography. Prepared under the auspices of the Committee on Sedimentation.

This chart was made to aid in the description of sedimentary rocks and for other purposes in which accurate color descriptions are necessary. It has been in preparation since 1925, and is now ready for distribution, having just been completed by the lithographers, Hoen and Company, of Baltimore, Md. It consists of two 5 in. by 8 in. sheets with 114 three-fourths inch blocks of color printed on a gray background. The colors were selected from Ridgway's "Color Standards and Color Nomenclature" to cover the range of colors to be found in rocks, especially in sedimentary rocks, and have been arranged to conform as nearly as possible to Ridgway's system.

Price: 1 chart, $0.75; 5 charts, $3.50; 10 charts, $6.50; 25 charts, $15.00; 50 charts, $29.00; 100 charts, $55.00.

Orders should be sent to Chairman, Division of Geology and Geography, National Research Council, B and 21st Sts., Washington, D. C., and checks made payable to National Research Council.

BOOKS RECEIVED.

Analysis of West Virginia Coals. Pp. 343, index. U. S. Bureau of Mines, Tech. Paper 405, 1928 (Dec.). Price, 20 cts.

Summarized Data of Copper Production. By C. E. JULIHN. 32 pp. and chart. U. S. Bureau of Mines, Economic Paper No. 1, 1928 (Dec.). Price, 10 cts.

The first of a new series of economic papers. A valuable compilation of copper production since 1800.

Surveying, Theory and Practice. By R. E. DAVIS, F. S. FOOTE, and W. H. RAYNER. Pp. 1016, figs. 574, tables. Limp leather binding. McGraw-Hill Book Co., New York, 1928. (Jan., 1929).

An up-to-date, complete text.

The Two Solar Families: the Sun's Children. By T. C. CHAMBERLIN. Pp. 311, figs. 46. University of Chicago Press, 1928 (Nov.). Price, $2.50.

The genesis of the planetary and cometary families, with a review of previous theories. Written for popular reading, but still heavy to digest.

Underpinning Science: An Engineer's Ideas on What Actuates the Universe. By EDWARD GODFREY. 76 pp. Published by the author, Pittsburgh, Pa. Price, $1.00. 1928 (Dec.).

A book of nonsense masquerading as science.

Diatomite—Its Occurrence, Preparation, and Uses. By V. L. EARDLEY-WILMOT. Pp. 182, figs. 31, pl. 16. Canada Dept. of Mines, Mines Branch Bull. 691. Ottawa, 1928 (Dec.).

General properties, uses, occurrence, tests, prices, and preparation of diatomite. Bibliography. An excellent treatise.

The Geology of the Malvern Hills, New Zealand. By R. SPEIGHT. Clays and Sands, by S. Page. 72 pp., map and sections. Panoramic sketches. New Zealand Geol. Memoir No. 1, 1928 (Jan., 1929).

Physiography, stratigraphy, igneous rocks, coals, clays and sands, building stones.

SOCIETY OF ECONOMIC GEOLOGISTS

Award of Penrose Medal.

The third award of the Penrose Medal of the Society of Economic Geologists was made to Waldemar Lindgren in recognition of his "distinguished achievement in the geologic sciences." This medal was established in 1924 by R. A. F. Penrose, Jr., the first president of the Society. In awarding this medal to Professor Lindgren, many contributions to general geology are recognized, and not merely his outstanding work in economic geology. This medal has previously been awarded to the late T. C. Chamberlin and to J. H. L. Vogt.

The medal was presented to Professor Lindgren at a dinner of the Society held in New York on the evening of December 27, 1928. President Emmons spoke of Lindgren's many achievements, mentioning as the outstanding ones his contributions to Contact Metamorphism, Metasomatic Processes in Fissure Veins, and his textbook on Mineral Deposits. Dr. George Otis Smith spoke of Lindgren's work on the U. S. Geological Survey, and of his part in training many of the best geologists of the United States; and Dr. H. F. Bain spoke of his directing influence in the development of our knowledge of Economic Geology.

Officers and Members.

As a result of the recent election, the following officers have been elected:

President: M. R. Campbell.
Vice-President: Sydney Ball.
Councilors: H. G. Ferguson, Term expires in 1930.
J. T. Singewald, Jr., Term expires in 1930.

The other councilors, whose term expires in 1929, are B. S. Butler, David White, and W. E. Wrather.

The following have been declared elected to membership:

Joseph Peter Connolly	Leopold Reinecke
Joseph Lincoln Gillson	Hans Schneiderhöhn
Sir A. E. Kitson	Friedrich Schumacher
Hugh Exton McKinistry	David G. Thompson

Eighth Annual Technical Session.

The eighth annual technical session of the Society of Economic Geologists was held on December 28 and 29, 1928, at the American Museum of Natural History in conjunction with the meeting of the Geological

Society of America. On Friday afternoon, December 28th, the Society met jointly with the Mineralogical Society of America. The Society's technical sessions and dinner were well attended.

The program follows:

Friday, December 28

Joint Meeting with Mineralogical Society of America

G. L. English, Diamonds and diamond mines in South Africa. (Lantern slides.)

S. G. Gordon, The passing of the French Creek mines. (Lantern slides.)

S. G. Gordon, Remarks on Llallagua phosphates. (Lantern slides.)

Charles Palache, Paragenetic classification of the minerals of Franklin, N. J. (Lantern slides.)

Charles Palache, Comparison of the ore deposits of Långban, Sweden, with those of Franklin, N. J.

C. S. Ross and E. V. Shannon, The manganese minerals of a hydrothermal vein near Sparta, N. C.

W. T. Schaller, Halite-anhydrite intergrowths from Texas.

B. S. Butler and W. S. Burbank, Some relations between electrode potentials of elements and hypogene mineral deposition. (Lantern slides.)

J. T. Singewald, The problem of supergene cassiterite in Bolivian tin veins.

E. S. Moore, An unusual type of magnetite vein.

A. M. Bateman, Some chalcocite-covellite relationships.

A. A. Pegau, The Rutherford mines, Amelia County, Va.

A. C. Hawkins, New and unusual New Jersey mineral occurrences.

Saturday, December 29.

T. M. Broderick, Distribution of arsenic in the Michigan copper deposits.

T. M. Broderick, Zoning in the Michigan copper deposits.

E. S. Bastin, The Illinois fluorite deposits. (Lantern slides.)

J. E. Gill (introduced by Edward Sampson), Some gold occurrences in Fourniere and Malartic Townships, Quebec. (Lantern slides.)

E. L. Bruce, Sherritt-Gordon copper-zinc deposit, Northern Manitoba. (Lantern slides.)

Waldemar Lindgren, Silver ores of Huanuni, Bolivia.

A. O. Hayes, Further studies of the Wabana iron ores of Newfoundland.

S. B. Talmage (introduced by U. S. Grant), Significance of "unsupported" inclusions.

G. F. Loughlin and others, Gold reserves of the United States. (Preliminary statement.)

Symposium on methods of estimating ground water supplies.—In joint session with the Geological Society of America.

O. E. Meinzer, Outline of available methods.

W. N. White (introduced by O. E. Meinzer), Methods based on transpiration of plants.

D. G. Thompson, Methods applicable to artesian basins.

Society of Economic Geologists

Presidential Address. W. H. Emmons, The origin of the sulphide ores of the Mississippi Valley.

SCIENTIFIC NOTES AND NEWS

J. A. Bancroft has resigned his geology professorship in McGill University and will remain in Rhodesia.

F. W. Bradley has been elected president of the American Institute of Mining and Metallurgical Engineers for 1929.

Sir Albert E. Kitson has returned to the Gold Coast, Africa.

J. B. Scrivenor has received from the Royal Geological Society of Cornwall the award of the William Bolitho gold medal.

W. H. Newhouse, assistant professor of economic geology at the Massachusetts Institute of Technology, is going to South America for several months of mine examination work.

Arthur Notman is to make an extensive trip through South America.

A. C. Lawson has left for a trip to Siam.

Dr. Henry Louis has been re-elected president of the Institution of Mining Engineers for the coming year.

E. F. Burchard, of the U. S. Geological Survey, is in Florida investigating the fluorspar reported at De Funiak Springs.

G. F. Loughlin, of the U. S. Geological Survey, went to Colorado to attend the annual meeting of the Colorado Mining Association January 15 and 16.

T. A. Jaggar, of Hawaii, is in Washington, D. C.

L. T. Burwash, mining engineer, is engaged in work for the Canadian Government in the Arctic regions.

E. E. Campbell is consulting engineer for the Empire Gold Mines, on the properties lately acquired in the Oatman District, Arizona.

Charles H. Clapp, president of the University of Montana, gave an address before the Northwest Scientific Association at Spokane recently on the geology of the Mission, Swan, and Flathead Mountains, Montana.

G. Townsend Harley, mining engineer and geologist of Las Cruces, New Mexico, recently spent some weeks in Mexico on professional business, and examined several small mines in Arizona and New Mexico.

J. G. Flynn, mining engineer, formerly connected with the Bavaria Mining Company, is now superintendent of the Shattuck Denn Mining Corporation at Bisbee, Arizona.

Gilbert P. Moore has opened an office as consulting geologist at 25 Broadway, New York City.

F. Cushing Moore, mining engineer, has moved his office to 304 Standard Stock Exchange Building, Spokane, Wash.

Frederick G. Clapp has made recent trips to England and Switzerland and has returned to Paris, where his family is spending the winter.

Robert B. Sosman delivered an address on "Polymorphism in the System Fe-O," at the Washington Academy of Science meeting held at Washington on January 8.

The American Association of Petroleum Geologists will hold its annual meeting at Fort Worth, March 21–23. A large meeting is being planned for and considerable time is being set aside for complete discussion of controversial subjects of unusual current importance.

The Emmons Memorial Fellowship will again become available for applicants this year. Applicants should be qualified by training and experience to undertake the investigation of some problem in economic geology. Each candidate should submit with his application a definite statement of the problem which he proposes to study. The work will be under the oversight of the Committee, and may be undertaken at any institution which meets the approval of the Committee. The holder of the Fellowship must give his entire time to the problem selected. The results may be used as a dissertation for the degree of Doctor of Philosophy in an approved university. The stipend of the Fellowship will be about $1,500. Applications and accompanying testimonials should be submitted not later than March 1, 1929. Further information and application blanks may be obtained from the Committee, consisting of Alan M. Bateman, Charles P. Berkey, and Waldemar Lindgren, or from the Secretary of Columbia University.

The Annotated Bibliography of International Literature on Economic Geology is now in preparation, the minimum sum required having been raised by the committee. The first number, covering the literature of 1928, should be published around June 1st. It will at first appear semi-annually, and will cover the literature of ore deposits, petroleum, coal, and other non-metallic products. Its scope will be larger than its title implies, since much areal work that includes economic products must be cited.

The Geological Society of America held its 41st Annual Meeting at New York City, Dec. 26–29, 1928, in the rooms of the American Museum of Natural History and under the joint auspices of the American Museum of Natural History, Columbia University, and New York University. The meetings this year were in affiliation with the American Association for the Advancement of Science; the Mineralogical Society, Paleontological Society, and Society of Economic Geologists also held meetings concurrently.

The technical sessions, extending over four days, were well attended, and some lively discussions took place, helped by the presence of R. A. Daly. Some 90 papers were presented. In addition, 47 papers were

presented before the Paleontological Society, 30 before the Mineralogical Society, and 26 before the Society of Economic Geologists. The principal addresses were: Address of welcome, by Henry Fairfield Osborn, President of the American Museum of Natural History; Presidential address, by Bailey Willis, on Continental Genesis; address by Charles Schuchert, retiring Vice-President of Section E, on Geological History of the Antillean Region; address by Esper S. Larsen, retiring President of the Mineralogical Society, on Temperature of Magmas; address by W. H. Emmons, retiring President of Society of Economic Geologists, on The Origin of the Sulphide Ores of the Mississippi Valley.

The annual banquet, held at the Hotel Astor, was the most largely attended in the history of the Society. The second award of the Penrose Medal of the Geological Society of America was made to Dr. Jakob Johannes Sederholm, Director of the Geological Commission of Finland, the presentation address being given by Frank D. Adams. There was an interesting and welcome innovation in the speeches. Four outstanding speakers were chosen to present brief addresses on subjects in which geologists are interested. John C. Merriam spoke on Nature, Research, and Education; Arthur L. Day, on Twenty-Five Years of Geophysics; F. R. Moulton, on Astronomy and Geology; and R. A. Millikan, on Sources of Energy.

The local committee are to be congratulated upon the success of the arrangements.

Edwin Binney, Jr., Yale 1921, Ph.D. 1925, died Dec. 29, at Pasedena, California. His body was buried at his home at Sound Beach, Conn.